# Chapter 3

# Sustainable Urban Water Management

James P. Heaney, Len Wright, and David Sample

## Introduction

Water supply, wastewater, and stormwater systems are explored in this chapter, first individually and then looking at them in an integrative manner. Key areas of potential integration of these three functions are in reuse of wastewater and stormwater to reduce the required net import of water for water supply. The literature review summarizes previous and on-going work nationally and internationally to develop more sustainable urban water management systems.

## Systems View of Urban Water Management

The mid 1960's were a period of great change in the water resource field in the United States. The 1964 Water Resources Research Act established the Office of Water Resources Research (OWRR) with a mission of promoting interdisciplinary research because the individual federal agencies were only looking at their mandated piece of the total water system. Also, the 1965 Water Resources Planning Act established river basin commissions to better integrate water resources planning across federal agencies. Great strides were made in urban water and environmental management during the 1960's and 1970's because of strong federal support for research, a national mood to look at revitalizing our cities and restoring the environment, and the concomitant emergence of the systems approach and essential computer hardware and software.

The leadership in urban water resources during the early years can be traced to the ASCE Urban Water Resources Research Council (UWRRC) headed by M.B. McPherson. With funding from OWRR and the National Science Foundation (NSF), the UWRRC sponsored research conferences and numerous research projects dealing with a wide variety of urban water resources issues. The early results are published in McPherson et al. (1968). They pointed out that:

> **A single aspect research approach is totally inadequate and, indeed, is entirely inappropriate, for resolving multi-aspect problems. The former simplistic approach of regarding a unit of water as a fixed entity, such as stormwater, must be abandoned for that same unit at a different point in time will be categorized as water supply, recreation, esthetics, etc., perhaps several times before leaving a given metropolis.**

The ASCE UWRRC defined urban water resources to consist of:

1. Urban water uses:
   - Water supply (domestic, commercial, agricultural and for fire protection).
   - Conveyance of wastes (from buildings and industries).
   - Dilution of combined and storm sewerage system effluents and treatment plant effluents (by receiving bodies of water).
   - Water-oriented recreation and fish management.
   - Aesthetics (such as landscaped creeks and ponds in parks and parkways).
   - Transportation (commercial and recreational).
   - Power generation.

2. Protection of urban areas from flooding:
   - Removal of surface water at the source.
   - Conveyance of upstream surface water through the area.
   - Barricading banks, detaining or expressing flow natural streams to mitigate spillover in occupied zones of flood plain.
   - Flood proofing of structures.

3. Manipulation of urban water:
   - Groundwater recharge.
   - Recycling of water.

4. Pollution abatement in urban areas:
   - Conveyance of sanitary sewage and industrial wastes in separate sewerage systems.
   - Interception of sanitary sewage and industrial wastes.
   - Interception and treatment of storm sewer discharges or combined sewer overflows.
   - Reinforcing waste assimilative capacity of receiving water bodies.
   - Treatment of sanitary wastes at point of origin.

5. Interfacial public services:
   - Snowstorm and rainstorm traffic routing.
   - Street cleaning scheduling.
   - Snow removal strategies.
   - Lawn irrigation conservation.
   - Air pollution control.

The review of the integrated approach to urban water systems, which was in vogue in the late 1960's and 1970's, indicates that these researchers had scoped the problem very well. The spatial scale for these early systems studies tended to be macro in that it encompassed the entire urban area with a view towards finding the most cost-effective overall system. This approach was compatible with federal infrastructure funding patterns that required that the funded projects be part of an overall transportation or wastewater master plan for the entire urban area.

A systems approach to urban water management was described by Jones in 1971 (see Figure 3-1). McPherson (1973) argued that developing an urban water budget was an essential first step in using a systems approach as shown in Figure 3-2. Concurrently, researchers at Resources for the Future were stressing the use of a materials balance approach for inventorying and evaluating the generation and disposal of "residuals" or the quality constituents associated with transport in the air or water (Kneese, Ayres, and d'Arge 1970). A more recent summary of the residual management approach and a comprehensive catalog of models is presented in Basta and Bower (1982). Heaney (1994) presents an overview of these early studies.

**Sustainability Principles for Urban Water Infrastructure**

With regard to urban development in general and urban water systems in particular, Grottker and Otterpohl (1996) list the following general principles for providing sustainable development:

For the same or more activities, use less energy and material.

- Do not transfer problems in space or time to other persons.
- Minimize degradation of air, water, and land.

Application of these principles to urban water systems yields the following principles (Grottker and Otterpohl 1996):

1. Minimize the distance of water and wastewater transportation.
2. Use stormwater from roofs, preferably for water supply, instead of infiltrating or
   discharging it.
3. Do not mix the human food cycle with the water cycle. Do not mix waste waters
   of different origin.
4. Decentralize urban water systems and do not allow human activities with water if
   local integration into the water cycle is not possible.
5. Increase the responsibility of individual humans for their impacts on local water and wastewater systems.

THE SYSTEMS APPROACH TO URBAN WATER RESOURCES

THE URBAN COMPLEX IS THE BASIC SYSTEM:

The urban complex is people and serves people.

THE URBAN WATER RESOURCE IS A SUBSYSTEM IN THE BASIC URBAN SYSTEM:

To address the urban water resource as an independent system, even for convenience, may lead to dangerously narrow conclusions.

TRADITIONAL THINKING OF WATER SUPPLY, DISTRIBUTION, SEWAGE, FLOOD CONTROL, AND RECREATION AS SUB-ORDERS MAY BE INAPPROPRIATE:

These are interdependent service functions.
Perhaps the following breakdown might prove better:
The complete water cycle.
The environment, including people.
The ecology, including people (if separable from environment).
Public and private economies.
Management.

GENERALIZATIONS AT THE SUB-SUB-SUBSYSTEMS LEVEL COULD DEFEAT THE OBJECTIVES OF THE SYSTEMS APPROACH:

The progress of science is measured by development of details. Research contributions typically come from multiple minute steps--not from giant strides forward.
Rewarding concepts, innovations and improvements will originate essentially at the sub-sub-subsystem level.

TEMPTATIONS TO GENERALIZE, TO INERRELATE ONLY WITHIN THE FINITE CAPABILITY OF A MACHINE, AND TO IGNORE "INTANGIBLE" RELATIONSHIPS LACKING HARD DATA, MUST BE AVOIDED:

Neither a model nor a machine can think.
Man cannot excuse his failure to think.

**Figure 3-1**. Early view of the systems approach to urban water management (Jones 1971).

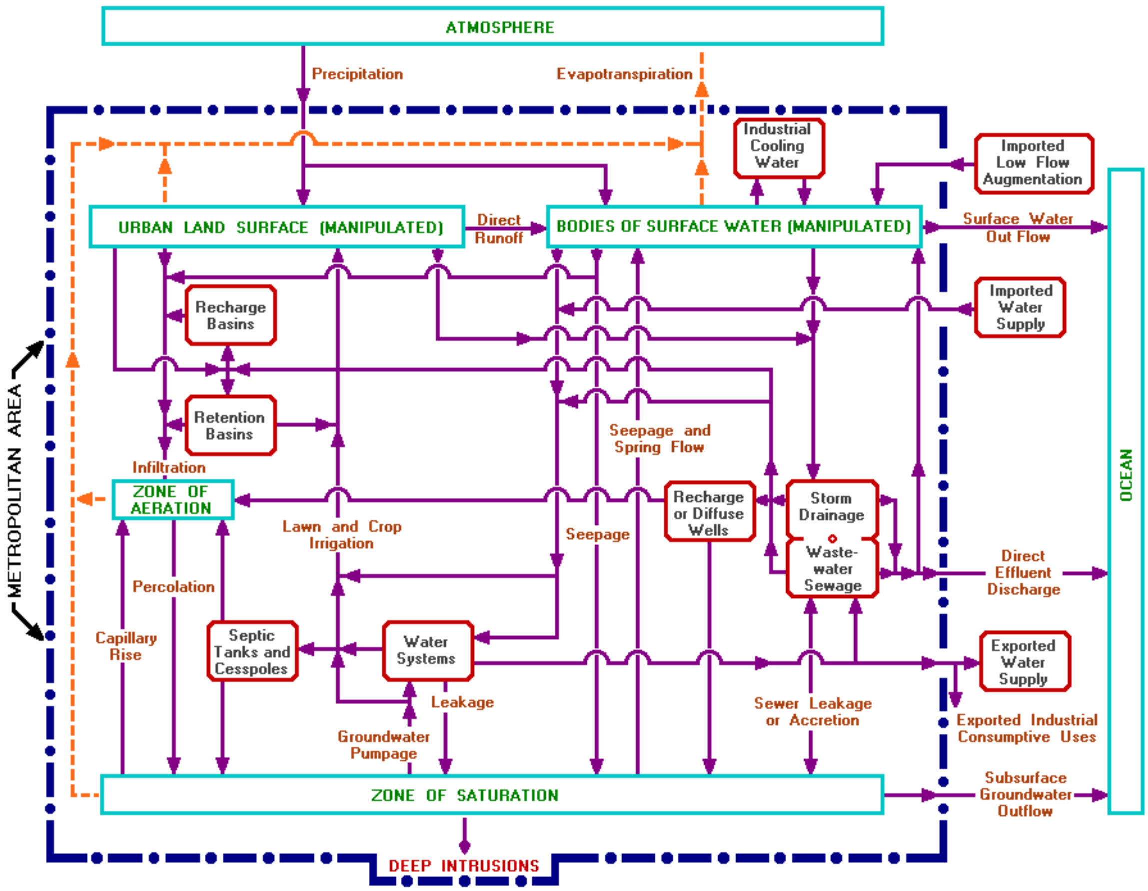


**Figure 3-2**. Water budget for urban water systems (McPherson 1973).

Sustainability has become popular as a general goal of future societies in general and environmental and economic systems in particular. A recent issue of Water Science and Technology featured numerous articles by European authors on the theme of “Sustainable Sanitation” (Henze et al. 1997). They could not find an operational definition of sustainability as it applies to urban water problems. Several authors did strongly advocate taking an holistic view of urban water systems ranging from water supply to wastewater and stormwater collection, treatment, and disposal.

Clark, Perkins, and Wood (1997) have developed and applied concepts of sustainability to evaluating alternative futures for the water system in Adelaide, Australia. This effort is the largest known case study of a group that is taking an integrative look at this problem. The purpose of the Water Sustainability in Urban Areas (WSIUA) project is to investigate the feasibility and benefits of progressive replacement of the existing large scale, single purpose water systems with replicated small scale, multipurpose water systems. These water systems consist of water supply, wastewater and stormwater. The key concepts explored in this study are

(Clark et al. 1997):

1. Adoption of a long planning cycle compatible with the life span of major components of the water systems.
2. Planning water systems to achieve multiple objectives-environmental, social, and economic.
3. Viewing water as a valuable resource warranting conservation and efficient utilization.
4. Undertaking water planning which seeks efficiency gains through taking a total water cycle approach on a local and regional basis as the best means of meeting multiple objectives.
5. Integrating water systems as appropriate to achieve efficiencies through infrastructure cost sharing.
6. Localizing water systems to achieve efficiencies through maximizing local opportunities.
7. Utilizing rainwater capture, effluent recycling and groundwater storage to maximize system resilience.
8. Franchising the operation of small scale systems as the best means of balancing cost competition with maintenance of adequate reliability and public health standards.
9. Recognizing the organizational and social implications of integrated local water systems.

## Urban Water Budget

### *Literature Review*

Water budgets have become popular in recent years as water professionals attempt to do more holistic evaluations of urban water systems. Grimmond et al. (1986) present a schematic of the components of the urban water budget as shown in Figure 3-4.

Stephenson (1996) cites three impacts of urbanization on stormwater runoff:

- Increased stormwater runoff.
- Recession of the water table.
- Shorter response time due to imperviousness.

He compares the water budgets of an undeveloped catchment with an urbanized catchment in Johannesburg, South Africa. The results show the expected increase in direct runoff and the need to import water for water supply. He also cites an urban water budget of a suburb of Vancouver, B.C. (Grimmond and Oke 1986).

Nelen et al. (1996) describe the planning of a new development for about 10,000 people in Ede, Netherlands. The three underlying environmental principles are sustainability, quality, and ecology. This area has a high groundwater table so groundwater management is an important part of the project. They plan to incorporate water-conserving hardware and divert the more polluted stormwater into the sanitary sewer. In addition, they are considering a dual water supply system.

Fujita (1996) describes efforts in Japan to encourage stormwater infiltration. The multiple objectives of this approach include:

1. River flow maintenance.
2. Springwater restoration.
3. Water resources guarantee.
4. Ground subsidence prevention.
5. Groundwater salination prevention.

Herrmann and Klaus (1996) do general water and nutrient budgets for urban water systems including stormwater. Imbe et al. (1996) performs a water budget analysis to determine the impact of urbanization on the hydrological cycle of a new development near Tokyo, Japan. This development is trying to minimize hydrologic impacts by encouraging infiltration systems and storing rainwater. Mitchell et al. (1996) describes a water budget approach to integrated water management in Australia. Budgeting is done at the individual parcel, neighborhood, and wider catchment scale. On-site management options include providing rain and graywater storage.

Clark et al. (1997) uses a water budget approach to evaluate decentralized urban water infrastructure for Adelaide, Australia.

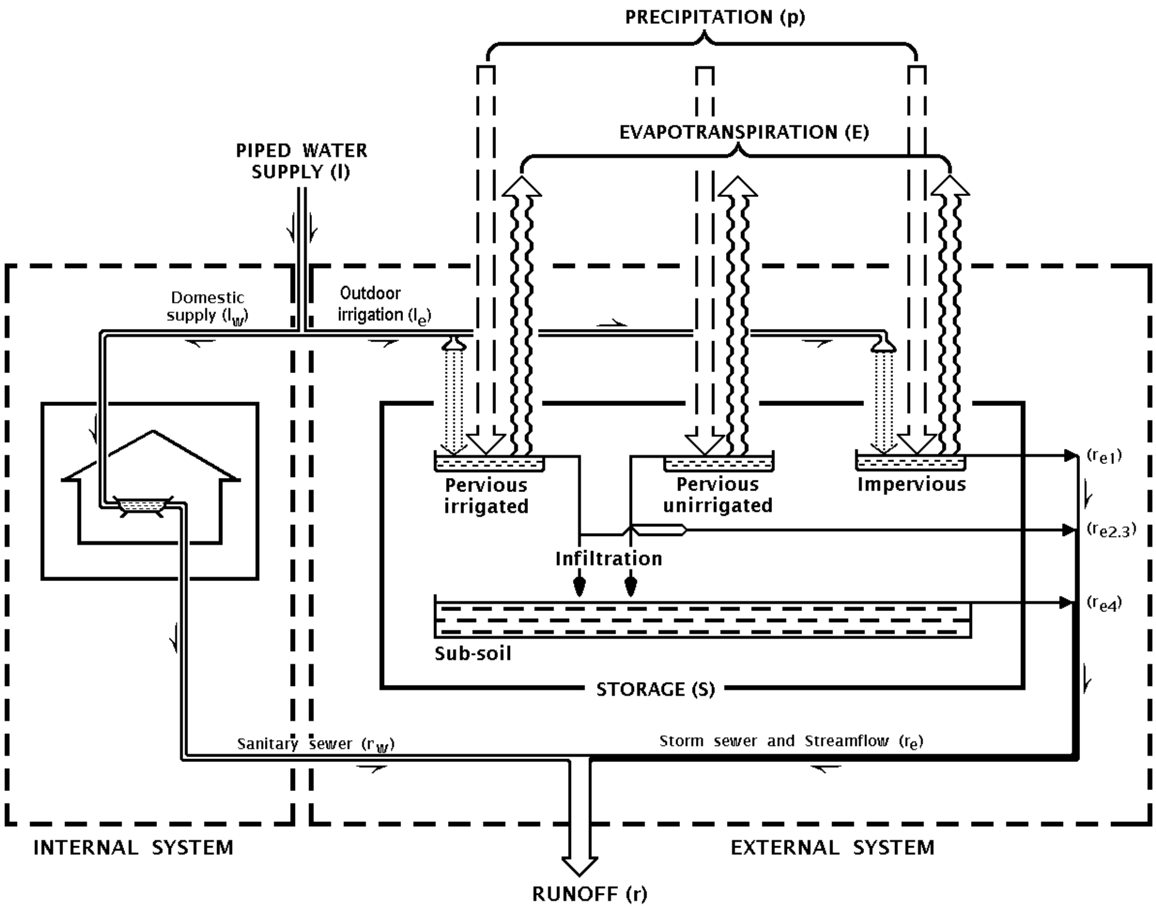


**Figure 3-3**. The urban hydrologic system (Grimmond et al. 1986).

### *Dry Weather Urban Water Budget*

Urban water use, wastewater, and urban stormwater are interdependent. Virtually all of the indoor water use is discharged to separate or combined sewers. The total quantity of wastewater is strongly influenced by infiltration and inflow, which often increase as a result of wet-weather conditions. Outdoor urban use for irrigation of plants makes pervious areas wetter and reduces the potential soil moisture storage available during wet weather periods. However, properly managed, a significant portion of urban stormwater can be directed onto pervious areas to reduce irrigation needs. These interactions and the potential for better integration of uses are described in this section.

The residential water demand data presented in this study are based on the results of a national study sponsored by the American Water Works Association Research Foundation (AWWARF) and 12 participating cities. Using an innovative monitoring and data logging system, detailed water use was monitored for approximately 1,200 houses in 12 cities. Each house was monitored for two weeks in a warmer period and 12 weeks in a colder period. Readings were taken every 10 seconds and converted into individual water using events using specially developed software. This work was finished in April 1998. This project is referred to as the North American End Use Study (NAREUS) project. Descriptions of this effort can be found in DeOreo et al. (1996), Harpring (1997), Mayer et al. (1997), Stadjuhar (1997), or by visiting the homepage of Aquacraft at www.aquacraft.com. The summary results of this water use study are presented in Table 3-1 that describes overall water use in the 12 cities, and Tables 3-2 and 3-3 that present the city summaries for each sampling period so that the reader can see the difference between the results for the warmer versus the colder periods.

### Indoor Urban Residential Water Use

The results of the NAREUS project indicate an average indoor water use of 63.2 gallons per capita per day (gpcd) with a range from 49 to 73 as shown in Table 3-1. Perusal of Tables 3-2 and 3-3 indicates that indoor water use does not vary significantly between winter and summer. Indoor residential water use per capita is quite stable in the United States reflecting the fact that indoor water use is for relatively essential purposes. These results are quite similar to previous studies of indoor water use. Based on a nationwide evaluation, Maddaus (1987) concluded that indoor residential water use averaged 60 gpcd. Studies of the expected value of wastewater into sewers likewise report an average of 60 gpcd. Toilets account for the largest percentage of indoor water use in all three studies followed by clotheswashers, showers, and faucets. The basis for the results shown in these three studies is described below.

Indoor water use does not vary significantly over the year. Some daily variability occurs between weekdays and weekends. The hourly distribution of indoor residential water use is shown in Figure 3-5 (Harpring 1997). Peak usage occurs during the early morning hours of 7 am to 10 am. Most of this peak is due to toilet and shower use. Toilet flushing continues at a similar rate for the rest of the day and into the evening. On the other hand, showers are taken primarily in the morning. Peak clothes washing activity occurs from 9 am to 1 pm. In general, water use in houses declines during the middle of the day because fewer people are at home. Use increases in the evening as people return home and prepare dinner, and then reaches its lowest level between midnight and 6 am when people are asleep. Interestingly, the British studies show use during the early morning hours for dish and clothes washing. The explanation for this usage pattern is that customers are taking advantage of lower electric rates during these hours (Edwards and Martin 1995). A general discussion of expected future trends in indoor water use follows.

**Table 3-1.** Summary of indoor water use for 12 cities in North America

All values in gallons per capita per day

| | 2.42 | 2.74 | 2.46 | 2.80 | 2.73 | 2.42 | 2.86 | 2.34 | 3.12 | 3.28 | 3.07 | 2.81 | 2.75 | 0.30 | 0.11 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boulder | Denver | Eugene | Seattle | San Diego | Tampa | Phoenix | Scottsdale/ | Waterloo | Walunt Valley | Las Virgenes | Lompoc | Average of | Std. Dev. Of | Coef. Of | |
| User Category | Colorado | Colorado | Oregon | Washington | California | Florida | Arizona | Tempe, AZ | Ontario | California | California | California | 12 cities | 12 cities | Variation | % of total |
| Baths | 1.58 | 1.51 | 1.29 | 0.66 | 0.57 | 1.12 | 0.95 | 0.95 | 1.35 | 1.05 | 1.28 | 1.41 | 1.16 | 0.30 | 0.26 | 1.83% |
| Clothes Washers | 13.76 | 14.65 | 16.02 | 10.82 | 15.77 | 13.49 | 14.80 | 13.70 | 12.70 | 13.90 | 16.30 | 15.75 | 14.30 | 1.59 | 0.11 | 22.64% |
| Coolers | 0.16 | 0.34 | 0.00 | 0.00 | 0.00 | 0.10 | 1.50 | 2.45 | 0.00 | 0.02 | 0.05 | 0.00 | 0.38 | 0.78 | 2.02 | 0.61% |
| Dish Washers | 1.42 | 1.07 | 1.26 | 0.82 | 0.83 | 0.60 | 0.75 | 1.05 | 0.75 | 0.60 | 0.87 | 0.82 | 0.90 | 0.25 | 0.28 | 1.43% |
| Faucets | 10.47 | 8.86 | 9.70 | 6.86 | 9.89 | 10.28 | 8.28 | 9.63 | 9.53 | 10.51 | 9.91 | 7.84 | 9.31 | 1.13 | 0.12 | 14.74% |
| Drinking water* | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | - | - | 0.58% |
| Hot Tubs | 0.02 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.05 | 0.20 | 0.00 | 0.30 | 0.26 | 0.05 | 0.08 | 0.11 | 1.34 | 0.13% |
| Leaks** | 3.38 | 6.62 | 8.70 | 4.14 | 4.56 | 9.75 | 12.45 | 14.80 | 6.20 | 7.35 | 9.25 | 8.46 | 7.97 | 3.37 | 0.42 | 12.62% |
| Showers | 13.17 | 12.73 | 13.73 | 10.10 | 9.14 | 9.92 | 11.90 | 11.75 | 8.15 | 11.60 | 11.06 | 11.46 | 11.22 | 1.65 | 0.15 | 17.76% |
| Toilets | 20.66 | 17.96 | 20.29 | 14.64 | 15.02 | 15.16 | 17.00 | 17.05 | 17.50 | 16.10 | 14.22 | 14.59 | 16.68 | 2.16 | 0.13 | 26.40% |
| INDOOR | 65.02 | 64.48 | 71.41 | 48.62 | 56.23 | 60.78 | 68.65 | 72.70 | 61.80 | 63.15 | 63.94 | 61.48 | 63.19 | 6.50 | 0.10 | 100.00% |
| Outdoor | 78.40 | 115.59 | 82.59 | 38.19 | 66.57 | 33.75 | 108.50 | 163.60 | 13.40 | 86.55 | 168.76 | 37.81 | 82.81 | 49.72 | 0.60 | |
| TOTAL | 143.42 | 180.07 | 154.00 | 86.81 | 122.79 | 94.53 | 177.15 | 236.30 | 75.20 | 149.70 | 232.70 | 99.28 | 146.00 | 53.74 | 0.37 | |

*Drinking water at 1.4 liters per capita per day

**Leaks are assumed to be indoor. They actually are a combination of indoor and outdoor.

***Unknown is assumed to be outdoor. It is actually a combination of indoor and outdoor.

**Table 3-2.** Summary of indoor and outdoor water use in Boulder, Denver, Eugene, Seattle, and San Diego

GALLONS PER CAPITA PER DAY

| | BOULDER, CO | | | DENVER, CO | | | EUGENE, OR | | | SEATTLE, WA | | | SAN DIEGO, CA | | | TAMPA, FL | | | Six City |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5/21 - 6/6/96 | 9/1 - 9/19/96 | Average | 6/5 - 6/21/96 | 10/29-11/14/96 | Average | 6/25-7/11/96 | 12/2-12/20/96 | Average | 7/17-8/1/96 | 1/8-1/24/97 | Average | 8/7-8/25/96 | 2/6-2/22/97 | Average | 9/30-10/17/96 | 3/5-3/20/97 | Average | Average |
| Persons/dwelling unit | 2.38 | 2.47 | 2.42 | 2.74 | 2.73 | 2.74 | 2.58 | 2.34 | 2.46 | 2.81 | 2.78 | 2.80 | 2.78 | 2.67 | 2.73 | 2.34 | 2.49 | 2.42 | |
| Baths | 1.2 | 1.9 | 1.6 | 1.5 | 1.5 | 1.5 | 1.2 | 1.4 | 1.3 | 0.9 | 0.8 | 0.9 | 0.3 | 0.8 | 0.6 | 0.8 | 1.4 | 1.1 | 1.2 |
| Showers | 12.6 | 13.8 | 13.2 | 13.4 | 12.0 | 12.7 | 13.2 | 14.3 | 13.7 | 11.4 | 8.8 | 10.1 | 8.4 | 9.9 | 9.1 | 8.4 | 10.4 | 9.9 | 11.5 |
| Clothes Washers | 14.9 | 12.6 | 13.8 | 14.9 | 14.4 | 14.6 | 15.3 | 16.7 | 16.0 | 11.0 | 10.6 | 10.8 | 17.1 | 14.4 | 15.8 | 14.7 | 12.3 | 13.5 | 14.1 |
| Dish Washers | 1.7 | 1.2 | 1.4 | 1.0 | 1.2 | 1.1 | 1.3 | 1.2 | 1.3 | 0.9 | 0.7 | 0.8 | 1.0 | 0.7 | 0.8 | 0.7 | 0.5 | 0.6 | 1.0 |
| Toilets | 18.2 | 23.1 | 20.7 | 17.6 | 18.4 | 18.0 | 20.1 | 20.5 | 20.3 | 15.6 | 13.7 | 14.6 | 14.9 | 15.1 | 15.0 | 15.3 | 15.0 | 15.2 | 17.3 |
| Faucets | 10.7 | 10.9 | 10.8 | 9.4 | 9.0 | 9.2 | 10.2 | 9.9 | 10.1 | 8.2 | 6.3 | 7.2 | 10.1 | 10.4 | 10.3 | 10.4 | 10.9 | 10.7 | 9.7 |
| Coolers | 0.2 | 0.1 | 0.2 | 0.7 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.1 | 0.1 |
| Hot Tubs | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Humidifiers | 0.0 | 0.0 | 0.0 | 0.5 | 0.3 | 0.4 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| Leaks | 2.5 | 4.3 | 3.4 | 3.4 | 9.9 | 6.6 | 8.4 | 9.0 | 8.7 | 3.3 | 5.0 | 4.1 | 2.5 | 6.6 | 4.6 | 6.3 | 13.2 | 9.7 | 6.2 |
| INDOOR | 61.9 | 68.1 | 65.0 | 62.4 | 66.6 | 64.5 | 69.6 | 73.2 | 71.4 | 51.4 | 45.9 | 48.6 | 54.4 | 58.1 | 56.2 | 57.9 | 63.7 | 60.8 | 61.1 |
| Irrigation | 82.0 | 73.9 | 77.5 | 217.0 | 13.3 | 114.6 | 159.0 | 3.6 | 81.3 | 73.4 | 1.4 | 37.4 | 91.7 | 34.1 | 62.9 | 18.0 | 35.3 | 26.7 | 66.7 |
| Swimming Pools | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.7 | 0.4 | 2.6 | 4.7 | 4.6 | 4.7 | 1.2 |
| Unknown | 1.4 | 0.3 | 0.8 | 1.1 | 0.8 | 0.9 | 1.0 | 1.6 | 1.3 | 0.9 | 0.7 | 0.8 | 1.2 | 1.0 | 1.1 | 2.5 | 2.4 | 2.4 | 1.2 |
| OUTDOOR TOTAL | 83.4 | 73.4 | 78.4 | 218.1 | 13.1 | 115.6 | 159.9 | 5.2 | 82.6 | 74.3 | 2.1 | 38.2 | 97.6 | 35.5 | 66.6 | 25.2 | 42.3 | 33.7 | 69.2 |
| TOTAL | 145.4 | 141.5 | 143.4 | 280.5 | 79.6 | 180.1 | 229.6 | 78.4 | 154.0 | 125.7 | 47.9 | 86.8 | 152.0 | 93.6 | 122.8 | 83.1 | 106.0 | 94.5 | 130.3 |

**Table 3-3.** Summary of indoor and outdoor water use in Phoenix, Scottsdale, Waterloo, Walnut Valley, Los Virgenes, and Lompoc

GALLONS PER CAPITA PER DAY

| | PHOENIX, AZ | | | SCOTTSDALE/TEMPE, AZ | | | WATERLOO, ONT | | | WALNUT VALLEY, CA | | | LAS VIRGENES, CA | | | LOMPOC, CA | | | Six City |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4/29 - 6/15/97 | 11/4-11/18/97 | Average | 5/20-6/3/97 | 12/2-12/18/97 | Average | 6/23-7/10/97 | 10/7-10/22/97 | Average | 7/29-8/12/97 | 1/6-1/20/98 | Average | 8/19-9/3/97 | 1/27-2/10/98 | Average | 9/8-9/23/97 | 2/24-3/9/98 | Average | Average |
| Persons/dwelling unit | 2.77 | 2.92 | 2.85 | 2.25 | 2.42 | 2.34 | 3.09 | 3.15 | 3.12 | 3.33 | 3.23 | 3.28 | 3.1 | 3.04 | 3.07 | 2.79 | 2.83 | 2.81 | 2.9 |
| Baths | 0.8 | 1.1 | 1.0 | 1.1 | 0.8 | 1.0 | 1.8 | 0.9 | 1.4 | 1.4 | 0.7 | 1.1 | 1.4 | 1.2 | 1.3 | 1.1 | 1.7 | 1.4 | 1.2 |
| Showers | 12.6 | 11.2 | 11.9 | 12.0 | 11.5 | 11.8 | 7.5 | 8.8 | 8.2 | 11.0 | 12.2 | 11.6 | 9.5 | 12.6 | 11.1 | 12.1 | 10.8 | 11.5 | 11.0 |
| Clothes Washers | 14.0 | 15.6 | 14.8 | 13.2 | 14.2 | 13.7 | 12.2 | 13.2 | 12.7 | 13.2 | 14.6 | 13.9 | 15.3 | 17.3 | 16.3 | 16.2 | 15.3 | 15.8 | 14.5 |
| Dish Washers | 0.7 | 0.8 | 0.8 | 1.1 | 1.0 | 1.1 | 0.7 | 0.8 | 0.8 | 0.5 | 0.7 | 0.6 | 0.7 | 1.0 | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 |
| Toilets | 17.1 | 16.9 | 17.0 | 16.9 | 17.2 | 17.1 | 16.4 | 18.6 | 17.5 | 15.6 | 16.6 | 16.1 | 13.3 | 15.1 | 14.2 | 15.3 | 13.9 | 14.6 | 16.1 |
| Faucets | 8.8 | 8.5 | 8.7 | 10.3 | 9.7 | 10.0 | 10.8 | 8.9 | 8.9 | 11.4 | 10.4 | 10.9 | 10.6 | 9.7 | 10.2 | 8.4 | 8.0 | 8.2 | 9.6 |
| Coolers | 2.5 | 0.5 | 1.5 | 4.7 | 0.2 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | | 0.1 | 0.0 | 0.0 | 0.0 | 0.7 |
| Hot Tubs | 0.0 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.5 | 0.1 | 0.3 | 0.5 | 0.0 | 0.3 | 0.1 | 0.0 | 0.1 | 0.1 |
| Treatment | 0.1 | 1.1 | 0.6 | 0.5 | 1.0 | 0.8 | 5.5 | 5.0 | 5.3 | 1.5 | 1.2 | 1.4 | 0.9 | 0.2 | 0.5 | 0.8 | 0.9 | 0.7 | 1.5 |
| Leaks | 14.6 | 10.3 | 12.5 | 13.8 | 15.8 | 14.8 | 7.3 | 6.1 | 6.2 | 6.9 | 7.8 | 7.4 | 9.3 | 9.2 | 9.3 | 8.0 | 8.9 | 8.5 | 9.8 |
| INDOOR | 71.2 | 66.1 | 68.7 | 73.7 | 71.7 | 72.7 | 62.3 | 61.3 | 61.8 | 62.0 | 64.3 | 63.2 | 61.6 | 66.3 | 63.9 | 62.6 | 60.4 | 61.5 | 65.3 |
| Irrigation | 138.8 | 68.2 | 103.5 | 234.6 | 70.1 | 152.4 | 24.1 | 1.0 | 12.6 | 154.4 | 11.8 | 83.1 | 288.4 | 33.7 | 160.0 | 60.7 | 13.0 | 36.8 | 91.4 |
| Swimming Pools | 4.5 | 2.7 | 3.6 | 10.4 | 6.6 | 8.5 | 0.0 | 0.0 | 0.0 | 3.5 | 0.2 | 1.9 | 10.5 | 2.4 | 6.4 | 0.0 | 0.0 | 0.0 | 3.4 |
| Unknown | 2.0 | 0.8 | 1.4 | 2.9 | 2.6 | 2.8 | 1.2 | 0.5 | 0.9 | 2.2 | 1.0 | 1.6 | 1.9 | 2.7 | 2.3 | 0.4 | 1.5 | 1.0 | 1.6 |
| OUTDOOR TOTAL | 145.3 | 71.7 | 108.5 | 247.9 | 79.3 | 163.6 | 25.3 | 1.5 | 13.4 | 160.1 | 13.0 | 86.6 | 298.8 | 38.7 | 168.8 | 61.1 | 14.5 | 37.8 | 98.4 |
| TOTAL | 216.5 | 137.8 | 177.2 | 321.6 | 151.0 | 236.3 | 87.6 | 62.8 | 75.2 | 222.1 | 77.3 | 149.7 | 360.3 | 105.1 | 232.7 | 123.7 | 74.9 | 99.3 | 161.7 |

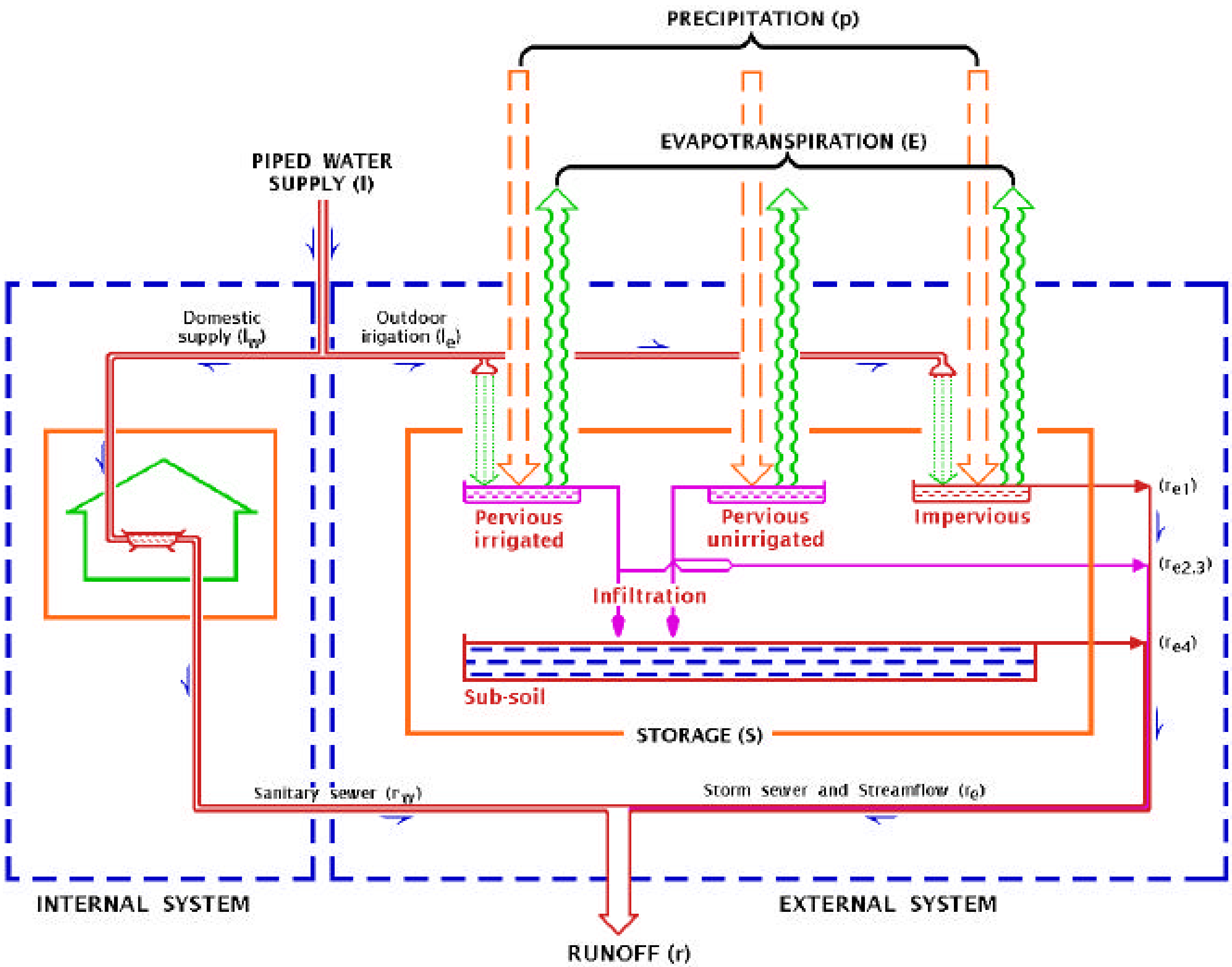


**Figure 3-4**. Hourly variability of indoor water use in 88 houses, Boulder, CO. (Harpring 1997).

***Toilet Flushing***: Toilet flushing is the most regular and predictable of all of the indoor water uses with an average of 16.7 gpcd and a range from 14.2 to 20.7 gpcd. Residents and guests will use the toilets every few hours if they are home. The only significant break in this pattern is during the night when people are asleep. Day to day variation in toilet flushing depends upon how many people are home at a given time. More people would be expected to be home on weekends and in the summer when school is not in session. Toilet flushing generates the black water that is the main source of pollutants at the wastewater treatment plant. The low variability of toilet use is good news from a design point of view since it is then only necessary to design for relatively small peaking factors. Also, low quality water can be used for toilet flushing. Thus, it is a good candidate for using reclaimed wastewater or stormwater.

Conservation options for toilets have focused on reducing the volume per flush from four to five gallons to 1.6 gallons which is mandated nationally in the plumbing codes. An important concern with regard to lower volume per flush is that people would double or triple flush. Based on a nationwide study of toilet flushing, Mayer et al. (1997) conclude that double flushing is a minor problem with low-flush toilets, occurring only about 6% of the time. Also, it does not appear that people will change their flushing patterns. British studies of the nature of toilet flushing indicate that only about 25 % of toilet flushes are to dispose of fecal material as shown in Table 3-4 (Friedler et al. 1996).

**Table 3-4**. Number of toilet flushes per day and proportion related to fecal flushes (Friedler et al. 1996)

| Flushes/day | Week Day | Weekend Day |
|---|---|---|
| **Fecal related** | 0.87 | 1.09 |
| **Other** | 2.24 | 2.43 |
| **Total** | 3.11 | 3.52 |

The diurnal pattern of fecal related flushes indicates that the majority take place between 6 am and 9 am. Thus, the savings result from fewer gallons per flush and not fewer flushes per day. The associated pollutant load would remain constant; accordingly, the wastewater concentrations would increase. Some concern exists that odors from sewers would be further intensified with the implementation of water conservation (Joyce 1995).

The volume per flush can be reduced to 0.5 gallons using pressurized systems. This technology may gain more widespread use in the future. Future toilets include the currently mandated low-flush (1.6 gallons) and ultra low-flush (0.5 gallons) conventional toilets. Johnson et al. (1997) describe an innovative toilet wherein feces and urine are collected in separate compartments. This toilet reduces water use and allows more efficient treatment of the two separate waste streams. Dual flush toilets are employed in Australia wherein the user selects whether to use more or less flushing water depending upon the need.

***Clothes Washing:*** Clothes washers use an average of 14.3 gpcd with a range from 10.8 to 16.3 gpcd. The traditional Monday wash day has been replaced by a more uniform pattern of clothes washing which is done throughout the day with peaks in the morning and early afternoon as was shown in Figure 3-4. More efficient clothes washers are expected to reduce water use per load by about 25 percent. The timing on clothes washing could be affected by electric or water utility rates, which provide time of day incentives and disincentives. As mentioned earlier, water users in Great Britain apparently wash late at night to take advantage of lower electricity rates.

***Showers and Baths:*** Showers (11.2 gpcd) are much more popular than baths (1.2 gpcd) for all 12 cities in the NAREUS study. For Boulder, CO, the morning shower is the predominant time for this activity as shown in Figure 3-5 (Harpring 1997). The other peak in showering occurs during the evening. Showers are taken on a daily basis in Boulder. Thus, no significant variability occurs from day to day. Drainage from showers can be used for lawn watering during the growing season of year. It is a significant source of reclaimable water and the timing of its entry into the wastewater collection system can be estimated accurately because the shower water is not stored during use.

The main conservation option for showers is to use low-flow shower heads. Results to date indicate only limited reduction in water use since users did not set the older shower heads to the higher flow rates. Federal law mandates a maximum flow rate for showers of 2.5 gallons per minute (gpm). Results of the NAREUS study indicate that most people set their shower flow rate below this level. Thus, conservation savings may not be that significant (Mayer et al. 1997). No significant change in duration of showers has been observed with the lower flow rate showers. Showers are also important as a major user of hot water.

***Faucet Use:*** Faucet use includes drinking water, water for washing and rinsing dishes, flushing solids down the garbage disposal, shaving, and numerous other personal needs. Faucet use averages 9.3 gpcd with a range from 6.9 to 10.5 gpcd. No breakdown among these uses is available although one can make educated guesses as to the amounts of water used for these purposes. Best estimates of actual drinking water use are in the range of 1.0 to 2.0 liters per capita per day with a mean of 1.4 liters per day (Cantor et al. 1987). Garbage disposals add about one gpcd to total indoor consumption (Karpiscak et al. 1990). Faucet use requires the highest water quality because it is the potable water source. Overall, faucet use is a small proportion of total use, which suggests the possibility of separate treatment and distribution systems for this source. Also, faucet use is relatively common during the day so equalizing storage requirements are low.

***Dishwashers:*** Dishwashers are a relatively minor water use and newer dishwashers are being designed to use less water to conserve energy and water.

Present per capita water use averages only 0.9 gpcd.

***Water Use for Cooling:*** For some houses, and for many commercial and industrial establishments, water use for cooling is a significant part of the water budget. Swamp coolers are used in the more arid areas of the United States. Karpiscak et al. (1994) estimate that residential evaporative coolers use about six gpcd in Tucson, AZ. Because of the relatively small number of houses using coolers, the average usage is quite low, only 0.4 gpcd.

**Outdoor Urban Residential Water Use**

Whereas indoor residential water use is very constant across the United States and does not vary seasonally, irrigation water use varies widely from little use to being the dominant water use. Also, it varies seasonally. The 12 cities in the NAREUS are not a representative sample of the United States with regard to climate types. Also, the amount of natural precipitation that occurred during the study periods can have a significant impact on the results. Nevertheless, the results certainly suggest the potential major impact of irrigation on average and peak water use.

A detailed evaluation of irrigation water use as a potential reuse of urban stormwater is presented in Chapter 8. This section only introduces the subject. Irrigation water use follows a definite pattern of high use rates in the morning and evening with low use rates during the day and late at night. Thus, these customers are following the common recommendations to not water during the middle of the day. Watering late at night is discouraged because of the noise from the sprinklers.

For the entire NAREUS study, outdoor water use averaged 82.8 gpcd, significantly more than the indoor water use of 63.2 gpcd. Studies of overall residential water use in Boulder and Denver show that outdoor water use averaged over the entire year exceeds indoor water use. Thus, outdoor water use can be a significant component of total annual average water use.

For the NAREUS study, Waterloo, Ontario is representative of conditions in the northeastern part of North America. During the summer, the outdoor water use averaged 25.3 gpcd compared to indoor water use of 62.3 gpcd. As expected the outdoor water use became negligible in the colder months, averaging only 1.5 gpcd in October.

At the other extreme, outdoor water use in Las Virgenes, CA averaged 299 gpcd, nearly five times the indoor water use of 61.6 gpcd during the summer sampling period. Thus, for residential areas in the more arid and warmer parts of the country, lawn watering is the largest single use on an annual average basis and is the dominant component of peak daily and hourly use during the summer months.

In the arid areas, evapotranspiration requirements are much greater than natural rainfall. In warmer parts of the country, even those with abundant rainfall, such as Florida, irrigation water use rates are high because of the long growing season which includes some dry periods. Irrigation water use is a major input to the urban water budget during the growing season. A growing number of people are installing automatic sprinkling systems. These systems tend to use more water than manual systems (Mayer 1995). Also, the timers on these systems are seldom adjusted. Thus, lawn watering occurs even during rainy periods. Experience with soil moisture sensors to control sprinkling use has been mixed. Automatic sprinkling systems do offer the potential for more efficient use of water if they are properly calibrated and operated (Courtney 1997).

The hourly pattern of total residential water use (indoor plus outdoor) for Boulder, CO is shown in Figure 3-5 (Harpring 1997). The study period from late May to early June included some rainy days. Peak hourly use between 6 and 8 am is caused predominantly by irrigation. Comparison of Figures 3-4 (indoor only) and 4-5 (total) indicates the importance of irrigation. The indoor water use at 6 am is about 7.5 gallons per house while the total water use at the same time is about 41 gallons per house. Thus, irrigation constitutes over 80% of the peak hourly use.

Options for reducing outdoor water use include using less water-loving plants, applying water more efficiently, reducing the irrigated area, and using nonpotable water including stormwater runoff and treated wastewater (Courtney 1997). Irrigation use has an indirect effect on urban runoff because it causes much wetter antecedent conditions, which increases the portion of rainfall that runs off. Sakrison (1996) projects a potential decrease of 35% in the demand for irrigation water in King County, WA if the higher density urbanization occurs. For King County, the main way that water use is managed is by restrictions on outdoor water use for landscaping. A maximum permissible evapotranspiration is allotted that forces the property owner to reduce the amount of pervious area devoted to turf grass. Stormwater run-on to the pervious area can be used for an extra credit. The amounts of irrigable area for three typical single family lot sizes are shown below.

The advantage of clustering is obvious from inspection of Table 3-5. The amount of irrigable area per house is reduced from 5,000 sq. ft. to 1,500 sq. ft., a reduction of 70%. This is the main savings in water use. However, from a stormwater runoff point of view, the imperviousness would increase.

**Table 3-5**. Typical lot sizes and irrigable area, King County, WA (Sakrison 1996).

| Density | Lot Size, (sq.ft.) | Irrigable Area Per lot (sq. ft.) | % of total |
|---|---|---|---|
| Low | 10,000 | 5,000 | 50 |
| Medium | 7,000 | 3,000 | 43 |
| High | 4,500 | 1,500 | 33 |

Lawn watering has increased in the U.S. as population migration occurs to warmer, more arid areas. Also, urban sprawl means much larger irrigable area per dwelling unit. Lawn watering needs are a dominant component of peak water use in urban areas. Reuse of treated wastewater and stormwater for lawn watering appears to be a very attractive possibility for more sustainable communities.

### Infiltration and Inflow

Infiltration and inflow are major issues in urban stormwater management. For example, the results of studies of Boulder, CO indicate that I/I is the major source of flow during high flow periods, which might cause SSOs (Heaney et al. 1996). Indeed, the actual sewage flow in the system is 8-10 mgd whereas flows reach 45-50 mgd during peak periods as shown in Figure 3-6. Thus, I/I is over four times the amount of legitimate dry weather flow (DWF). For Boulder, evidence exists that the I/I is clean ground water since pollutant concentrations drop as sewage flow increases. Thus, pollutant loads remain relatively constant. I/I is discussed in detail in Chapter 6.

### *Summary of Sources of Dry-Weather Flow into Sanitary and Combined Sewers*

Based on a sampling of nearly 1,200 houses in 12 North American cities, in which flows were measured for four weeks in each house, very accurate information is available on indoor water use patterns. Indoor residential water use averages 63.2 gpcd and remains constant throughout the year. Commercial, industrial, and public uses need to be added to this amount to estimate total water use. Essentially all of the indoor water use enters the sanitary or combined sewers. Outdoor water use is an important, and highly variable, water use.

Outdoor water use exceeds indoor water use on an annual average in more arid parts of the country. It also the primary cause of peak summer water use, and can range as high as five to six times indoor water use during these periods. Because of its seasonal nature, outdoor water use is a major component of the peak design flow as is water for firefighting.

Water conservation practices can reduce water use significantly, particularly outdoor water use. The increasingly high cost of treating water should encourage a new look at dual water systems and more aggressive reuse systems. Infiltration and inflow are the main unknowns in designing sanitary sewer systems. I/I varies widely within a city and across cities. Contemporary practice still allows much higher peak flows to account for this uncertainty.

The primary source of degraded water quality for residential uses is toilet flushing which accounts for about 30% of the DWF. Faucet water is also of concern, especially where garbage grinders are used. Thus, about 50 % of the DWF could be classified as “blackwater”. The remaining sources including showers, baths, clotheswashers, and dishwashers would be classified as “graywater”. The largest source of illicit “wastewater” is I/I which can range from a small fraction to several times DWF.

The conclusion from this simple water budget is that only a small portion of the wastewater entering sewers requires a high level of treatment. The remaining water could receive less treatment or does not need treatment because it is probably the infiltration of clean groundwater. This mass balance indicates that innovative changes in current practices may be very cost-effective.

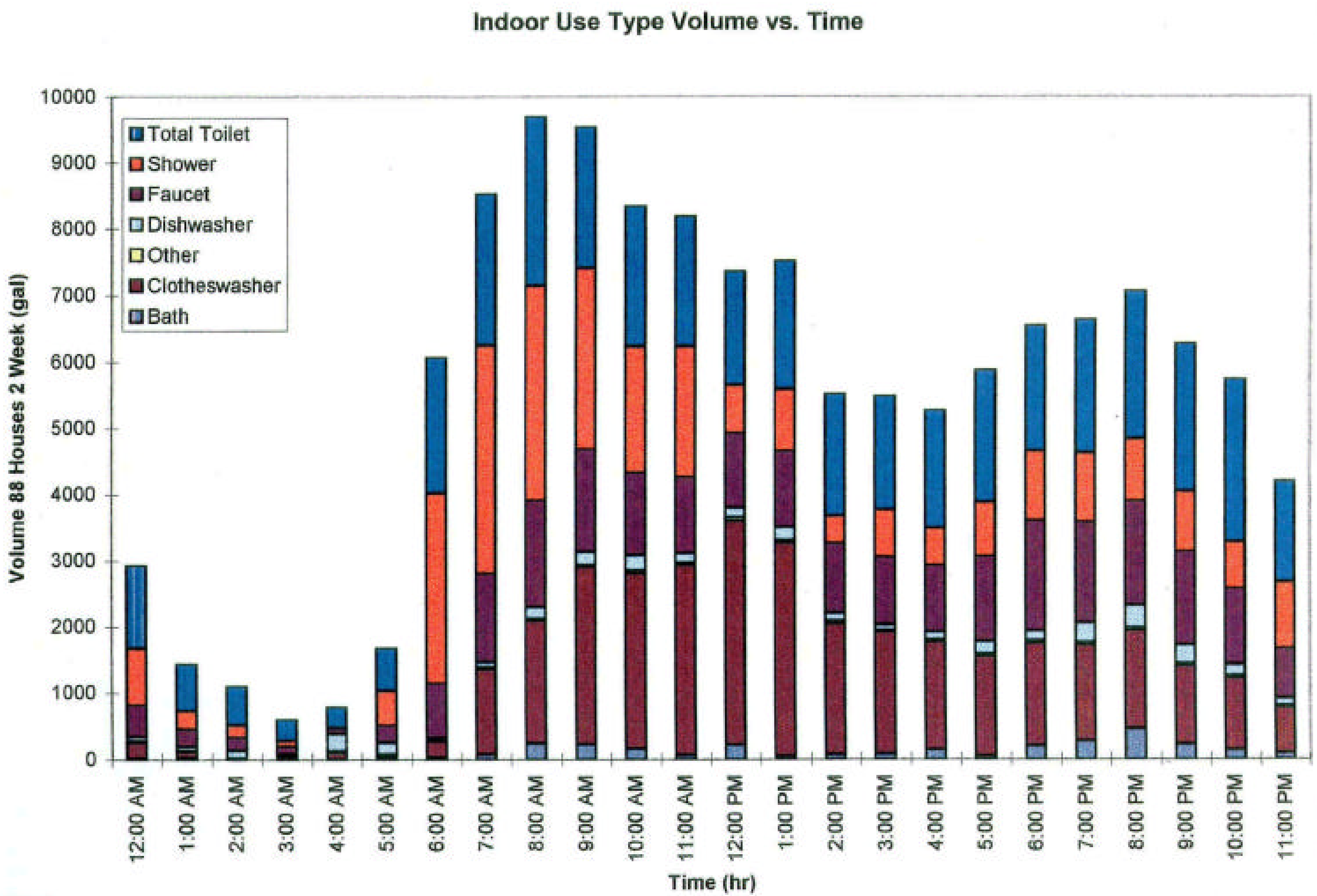


**Figure 3-5**. Weekday variability in total residential water use for 88 houses, Boulder, Co. (Harpring 1997).

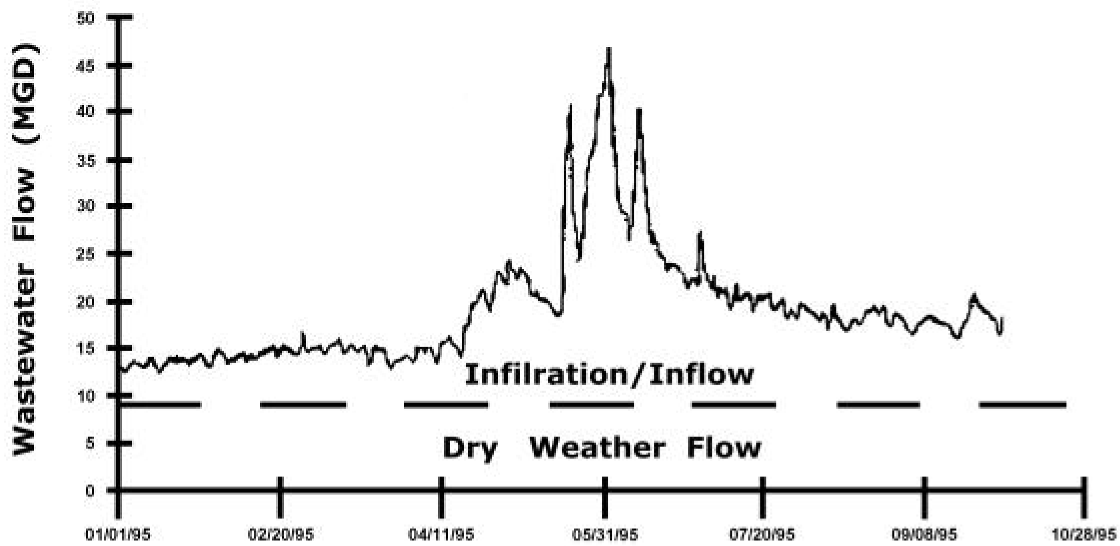


**Figure 3-6**. DWF., I/I and total wastewater flow, Boulder, CO, 1995 (Heaney et al. 1996).

**Quantities of Precipitation in Urban Areas**

Annual precipitation amounts for selected U.S. cities are listed in Table 3-6. The results of water budgets presented in the literature and water budgets for Denver and New York are presented in the remaining sections of this chapter.

**Results of Water Budget Case Studies**

***Arizona***

Two demonstration projects in Arizona provide examples of the results of aggressive water and energy conservation. The first project, which began in 1985, is located in Tucson, AZ, and is a demonstration house called Casa del Agua. The layout of the house and lot are shown in Figures 3-7 and 3-8 (Foster et al. 1988). Stormwater runoff from the impervious surfaces is directed to the adjacent pervious areas to provide supplemental irrigation water. Roof runoff is collected in rain cisterns with a total capacity of 14,000 gallons. Casa del Agua is a three bedroom, two-bathroom residence that has been retrofitted to incorporate low water use fixtures and water reuse systems. All graywater from the washing machine, tub, shower, lavatories, and one side of the kitchen sink is directed into a collection sump where it receives treatment (filtration) and then is stored until needed. Rainwater is a very high quality water source and is low in total dissolved solids making it ideal for use for evaporative cooling (Foster et al. 1988). It is also used for toilet flushing. The problem with rainwater, in Tucson, is that the supply is small and highly variable. The average annual precipitation for Tucson is only 11 inches (Karpiscak et al. 1990).

The baseline water use for an average Tucson house indicates a total daily use of 105 gallons per capita, of which 68 gpcd is for indoor use. All of this water is supplied from the municipal system. By comparison, the goal of the water conservation project was to import only 37 gpcd and to use 12 gpcd from rainwater and 30 gpcd from recycled graywater. The main reduction in indoor water use was to be achieved by flushing toilets with recycled water. The actual water use during the first year of the study was reduced by 33%. The total water use was broken down as follows: city water (77%), gray water (24%), and rain water (4%). Rainwater use was less than expected due to below average rainfall.

Graywater use was less than expected due to insufficient storage for gray water, necessitating its discharge periodically to the sanitary sewer. After four years of operation with some adaptation to improve performance, the use of municipal water was reduced by 66%. A key change was to convert one of the two 7,000 gallon rainwater collection tanks to a graywater storage tank (Karpiscak et al. 1990). As a result, very little graywater was discharged to the sanitary sewer system, greatly reducing the dry-weather wastewater flow to the WWTP. The use of graywater storage over the year indicates seasonal variability in the utilization with the storage full, or nearly full, in spring and then emptying during the main water use summer period of the year.

In addition to Casa del Agua, in Tucson, a newer demonstration house opened in Phoenix, AZ in May 1993. It is called Desert House and is located at the Desert Botanical Garden (Karpiscak et al. 1994). The goal of this demonstration house is to reduce energy and water use by 40%. This design will also focus on reducing peak summer water use. The main savings in indoor water use is due to reductions in toilet, shower, and washing machine use. The main reduction in outdoor water use results from using graywater for lawn watering. This 1,657 square foot, one story, single family
house is equipped with 1.5 gallon per flush toilets, 2.75 gallons per minute showerheads, and faucet aerators. Roof runoff goes to a 4 ,750 gallon cistern. The design size of the cistern had decreased significantly from the original size of 14,000 gallons in Casa del Agua. Desert House is designed for high visitor use so it is not operated in as routine a manner as Casa del Agua.

**Table 3-6**. Annual precipitation and days with rain for selected U.S. cities (US EPA 1979).

| State | City | Region | Annual Precipitation, in. | Annual Days w/ Rain | Average in/day |
|---|---|---|---|---|---|
| AL | Birmingham | East | 53.52 | 118 | 0.45 |
| CT | Harford | East | 42.43 | 128 | 0.33 |
| FL | Miami | East | 57.48 | 127 | 0.45 |
| GA | Atlanta | East | 47.14 | 115 | 0.41 |
| KY | Louisville | East | 41.47 | 122 | 0.34 |
| LA | New Orleans | East | 63.54 | 120 | 0.53 |
| MA | Boston | East | 42.77 | 128 | 0.33 |
| MD | Baltimore | East | 44.21 | 112 | 0.39 |
| NC | Charlotte | East | 43.38 | 110 | 0.39 |
| NY | Buffalo | East | 35.65 | 165 | 0.22 |
| NY | New York | East | 42.37 | 119 | 0.36 |
| OH | Cincinnati | East | 39.34 | 134 | 0.29 |
| OH | Cleveland | East | 32.08 | 156 | 0.21 |
| PA | Pittsburg | East | 36.87 | 146 | 0.25 |
| PA | Philadelphia | East | 42.48 | 115 | 0.37 |
| TN | Nashville | East | 45.00 | 120 | 0.38 |
| IA | Des Moines | Midwest | 31.06 | 105 | 0.30 |
| IL | Chicago | Midwest | 33.49 | 120 | 0.28 |
| IN | Indianapolis | Midwest | 39.69 | 124 | 0.32 |
| MI | Detroit | Midwest | 30.95 | 130 | 0.24 |
| MN | Minneapolis | Midwest | 24.78 | 113 | 0.22 |
| MO | St. Louis | Midwest | 36.46 | 104 | 0.35 |
| MO | Kansas City | Midwest | 34.07 | 98 | 0.35 |
| NE | Omaha | Midwest | 25.90 | 94 | 0.28 |
| TX | Austin | Midwest | 32.58 | 81 | 0.40 |
| TX | Dallas | Midwest | 34.55 | 80 | 0.43 |
| TX | Houston | Midwest | 45.26 | 103 | 0.44 |
| WI | Milwaukee | Midwest | 27.57 | 119 | 0.23 |
| CO | Boulder | Rocky Mtn. | 18.57 | 87 | 0.21 |
| NM | Albuquerque | Rocky Mtn. | 8.13 | 58 | 0.14 |
| UT | Salt Lake City | Rocky Mtn. | 14.74 | 87 | 0.17 |
| A K | Anchorage | West | 14.71 | 126 | 0.12 |
| AZ | Phoenix | West | 7.42 | 34 | 0.22 |
| CA | Los Angeles | West | 14.62 | 35 | 0.42 |
| CA | San Francisco | West | 20.78 | 67 | 0.31 |
| DC | Washington | West | 40.78 | 107 | 0.38 |
| HI | Honolulu | West | 23.96 | 99 | 0.24 |
| NV | Las Vegas | West | 4.35 | 25 | 0.17 |
| OR | Portland | West | 39.91 | 149 | 0.27 |
| WA | Seattle | West | 34.10 | 164 | 0.21 |
| WA | Spokane | West | 17.19 | 118 | 0.15 |
| | | Mean | 33.30 | 109 | 0.31 |
| | | Max | 63.54 | 165 | 0.53 |
| | | min | 4.35 | 25 | 0.12 |

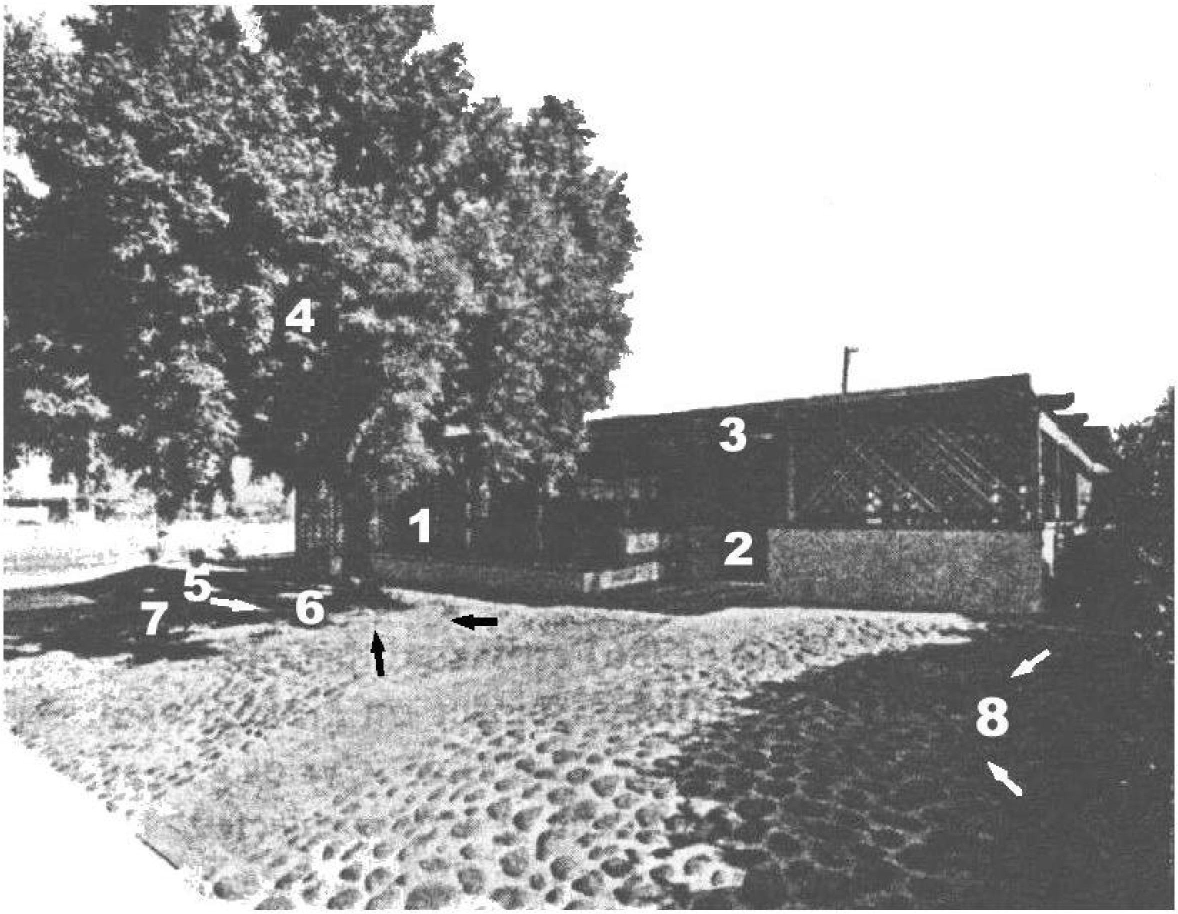


**Figure 3-7**. Front yard of Casa del Agua (Foster et al. 1988)
1) grape vine will grow over the lattice for more complete shade, 2) main entry defined and visually separated from street/driveway, 3) reed covered entry arbor provides shade from the west sun, 4) *Rhus lancea,* 5) *Cassia phyllodinea,* 6) *Lantana montevidensis,* 7) perimeter of yard is bermed to contain the rain and direct it to the plants, 8) cobblestone driveway directs rain to plants.

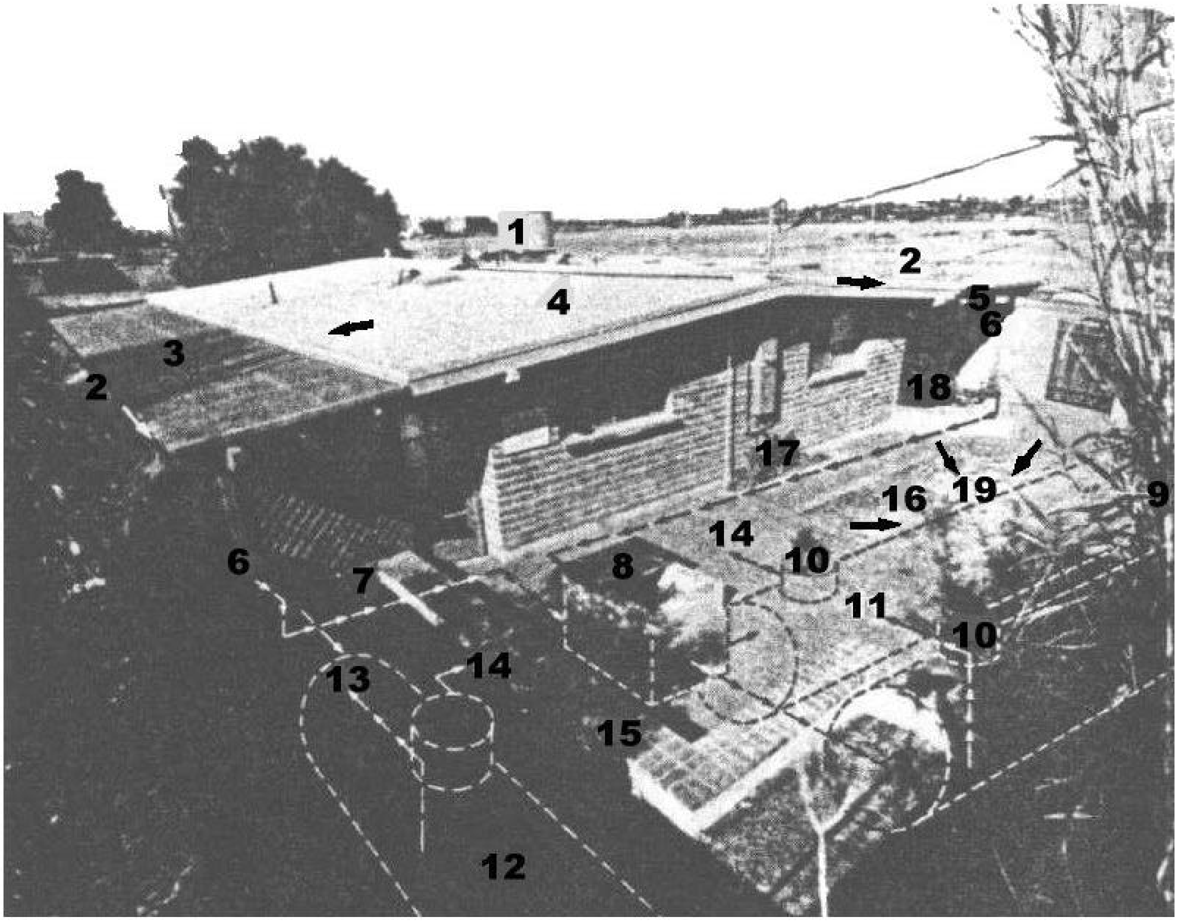


**Figure 3-8**. Back yard of Casa del Agua (Foster et al. 1988).
1) evaporative cooler, 2) new aluminum gutter, 3) new filon greenhouse roof, 4) existing gravel roof, 5) new filon porch roof, 6) new aluminum downspout, 7) pipe from downspout to filter, 8) concrete filter box with screen, 9) rain cisterns (14,000 gallons total), 10) cistern access, 11) supply to pump, 12) graywater cistern (800 gallons), 13) supply to pump, 14) overflow to sewer, 15) seat walls, 16) brick paving defined and visually separated from street/driveway, 17) *kalanchoe species,* 18) herb garden, 19) *Acacia pennacula*.

***Germany***

According to Grottker and Ottterpohl (1996), "the separation of feces and urine from the domestic waste water is identified as the most important step to a sustainable water concept." A 100-unit housing complex in Lubeck-Flintenbreite, Germany is being built using this concept. Key components of this innovative project are:

1. Storm water of private properties is re-used for toilet flushing, washing-

machines and irrigation in gardens. The overflow of stormwater storage is connected to the infiltration trenches of the road drainage. Two advantages of this approach are less potable water consumption and less detergent consumption.

2. Storm water from roads and other public surfaces is drained by infiltration depressions with trenches to the small creek. This method increases evaporation and retention of storm runoff.

3. Graywater is treated in aerated sand filters or constructed wetlands. The overflow is connected to the infiltration trenches of the public road drainage. Two advantages of this approach are using a simple treatment technique with high efficiency and waste water runoff retention.

4. Feces and other organic matter from households are transported by a vacuum system to a semi-central aerobic reactor with sludge storage, where the organic matter of 100 living units is treated. Vacuum toilets are used as inlets. Further, collected organic matter/waste is added to the anaerobic reactor. The treated sludge is stored and later carried to a farm. Three advantages of this approach are no I/I problem, less pollution in the treated sludge yields very high fertilizer, and biogas can be used in a semi-central heating system

This new system will be completely monitored for two years to do a final evaluation.

***Melborne, Australia***

Mitchell et al. (1996) used a daily water budget simulation model to evaluate the impact of on-site water management. They evaluated water use for two blocks in Melbourne, Australia. The attributes of each block are shown in Table 3-7.

**Table 3-7**. Attributes of two neighborhoods in Melbourne, Australia (Mitchell et al. 1996).

| Attribute | Neighborhood | |
|---|---|---|
| | Essendon | Scoresby |
| Rainfall, mm/yr | 591 | 887 |
| Rain, days/yr | 196 | 215 |
| Evaporative demand, mm/yr. | 1054 | 1054 |
| Soil Type | clay | silty clay |
| Area, sq m | 750 | 750 |
| Roof plan area, sq m | 203 | 203 |
| Paved area, sq m | 113 | 113 |
| Garden area, sq m | 434 | 434 |
| People/house | 3 | 3 |
| Type of garden | standard | standard |

The following retrofits were evaluated in these two areas:

- 13 kiloliter rain tank for storage of roof runoff for laundry, toilet, and garden water uses. Spillage is directed to the storm drainage network.
- Graywater from bathrooms and laundry is used for gardening through a sub-surface irrigation system. Overflows go to the wastewater sewer.

The simulated performance of the modified system is summarized in Table 3-8 (Mitchell et al. 1996).

**Table 3-8** Simulated performance of modified urban systems (Mitchell et al. 1996).

| **Attribute** | **Neighborhood** | |
|---|---|---|
| | **Essendon** | **Scoresby** |
| Water demand, kl/yr | 278 | 265 |
| Reduced demand for imported water, % | 41 | 49 |
| Reduced off-site stormwater runoff, % | 56 | 49 |
| Reduced wastewater runoff, % | 11 | 8 |
| Usage from rainwater tank, kl/yr | 84 | 107 |
| Rain tank deficit/demand | 0.48 | 0.3 |
| Use of graywater, kl/yr | 28 | 24 |
| Graywater deficit/demand | 0.65 | 0.65 |

The reduction in demand for imported water was 41 and 49% for the two systems while off-site stormwater runoff was reduced by 56 and 49% for the two neighborhoods. These results indicate the potentially major impact of on-site water management on overall water use.

### *Adelaide, Australia*

Adelaide is typical of other cities in that the water supply, wastewater, and stormwater infrastructure systems have developed independently of each other and now exist as large centralized systems. Adelaide has a separate sewer system. The demand for water in Adelaide, shown in Figure 3-9, indicates that direct contact needs are about 52 GL/a, 8 GL/a for process and manufacturing, 82 GL/a for gardens and other irrigation, and 18 GL/a for toilet flushing, or a total of 157 Gl/a. Thus, the majority of the water demand does not require high quality water. The potentially available local supply, shown in Figure 3-10, indicates 30GL/a from roof runoff, 95 GL/a from hillside runoff, 61 GL/a from street runoff, 52 GL/a from graywater effluent, and 24 GL/a from blackwater effluent, or a total of 260 GL/a. Thus, on the average, the potential local supply exceeds the demand, and the possibility exists for a locally sustainable system if the necessary storage, treatment, and redistribution facilities could be provided.

The monthly variability in demand, rural runoff, effluent, and urban runoff are shown in Figure 3-11. The present centralized system utilizes 550 kl per person in storage. According to calculations of Clark et al. (1997), the decentralized system would require only 150 kl per person to provide adequate water during a one in a 100 year drought. The overall proposed water budget components for the Adelaide system is shown in Figure 3-12.

Urban wastewater is being reused at several locations in Australia, (e.g., Rouse Hill near Sydney), with a first stage of 25,000 dwellings (Law 1997) and on a small scale at New Haven Village in Adelaide with 67 dwellings. New Haven Village is an innovative development of 65 medium density affordable dwellings that is designed as an implementation of the integrated approach (Clark et al. 1997). Key water management features include on-site treatment and reuse of household effluent, an innovative stormwater drainage system, and demonstration technology for an underground sub-surface irrigation system. With on-site treatment and reuse of household sewage and stormwater runoff, virtually no water leaves the site. The wastewater plant is located underground. Treated water is used for irrigation and toilet flushing, thereby reducing water demand by 50%. Two 22,500 liter underground storage tanks provide effluent storage. Sludge is disposed to a sludge thickening plant on site. Street widths have been reduced from 12.4 meters to only 6.8 meters. The stormwater is captured in a 40,000 liter underground concrete tank. Overflows go to an infiltration trench, and finally to a retention area for extremely heavy rainfalls. The tank delivers stormwater to the treatment plant at night for treatment.

Other larger demonstration projects are underway in Australia. Notable projects include New Brompton Estate in which roof runoff is being stored in an underground aquifer. Overall, the studies by Clark et al. (1997) demonstrate the feasibility of water self-sufficiency for the City of Adelaide with an annual rainfall of 600 mm, which is typical of average rainfall conditions in the United States.

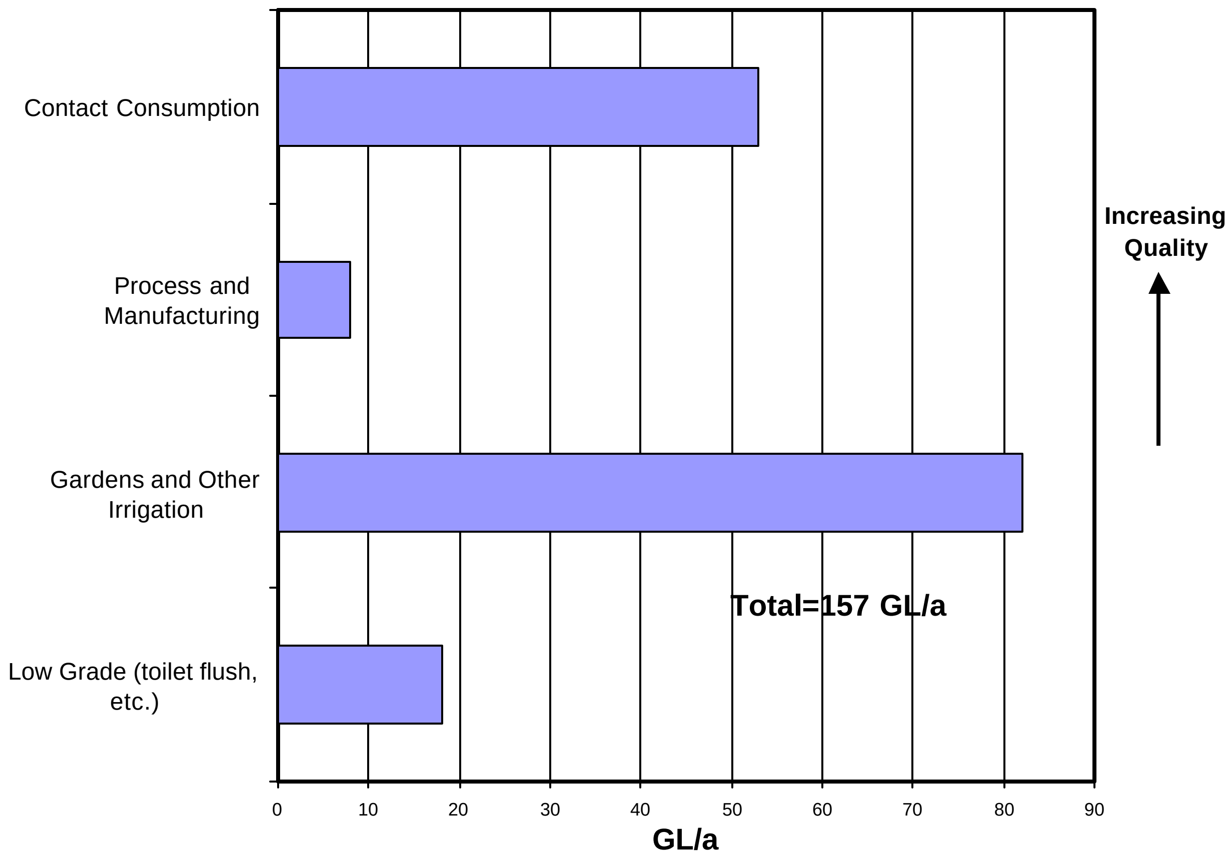


**Figure 3-9**. Consumption of water in Adelaide, Australia according to quality (Clark, 1997).

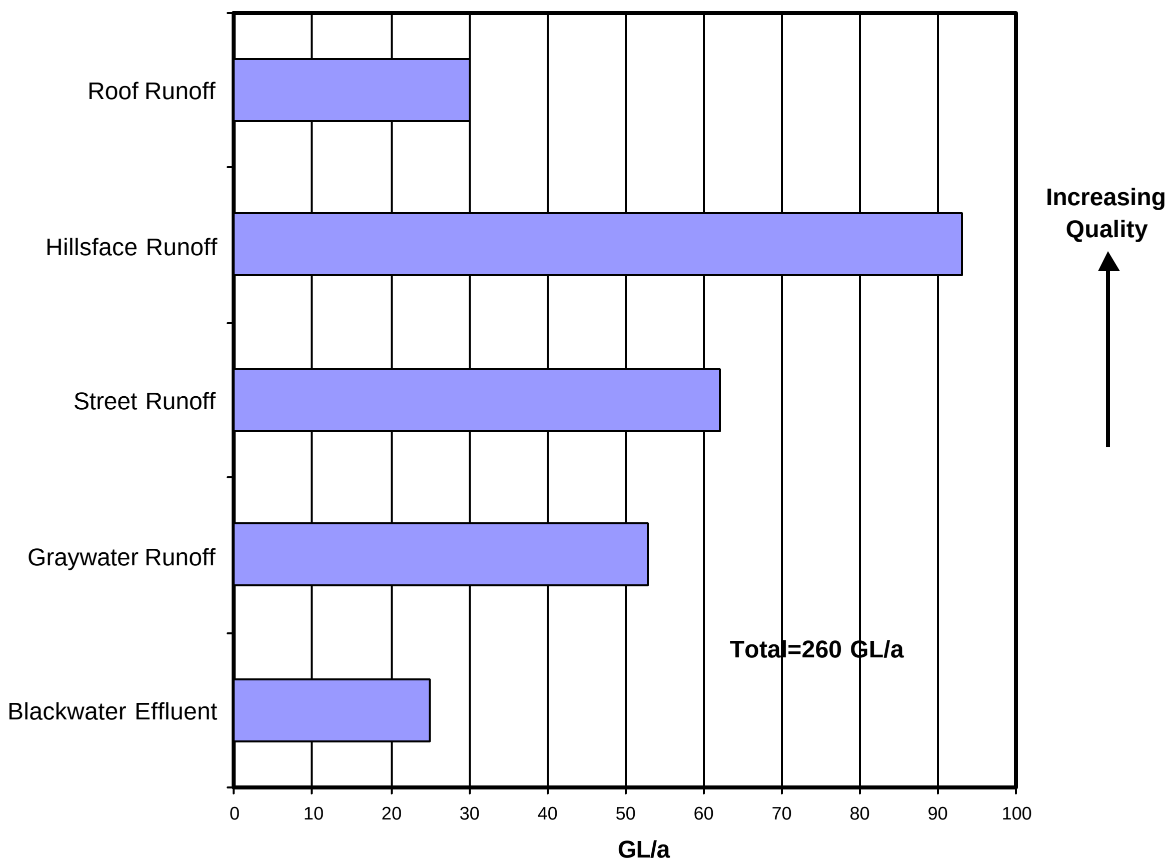


**Figure 3-10**. Availability of wastewaters in Adelaide, Australia according to quality (Clark, 1997).

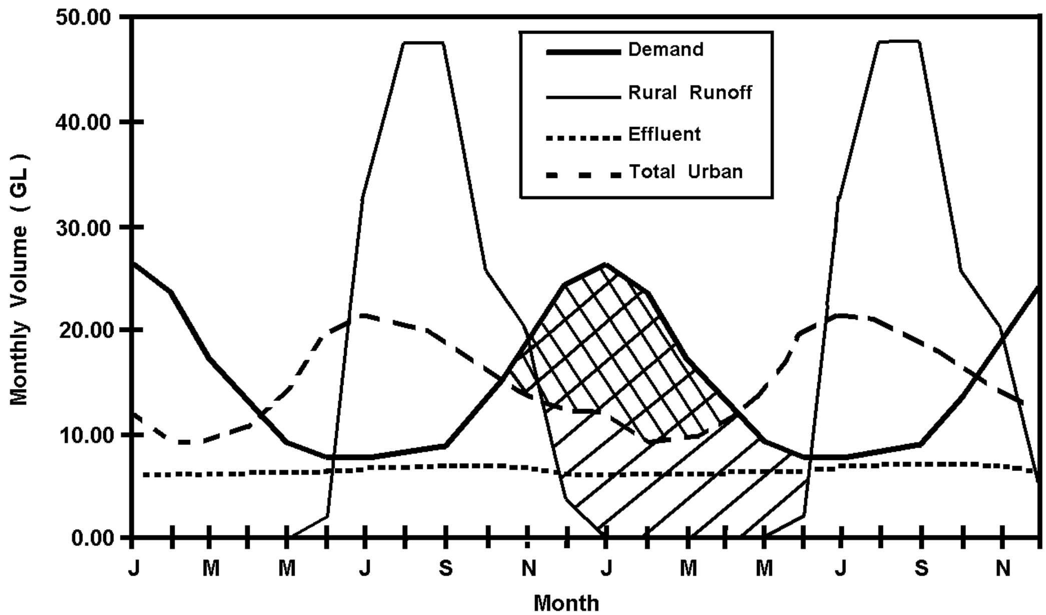


**Figure 3-11**. Typical monthly water supply and demand, Adelaide, Australia (Clark 1997).

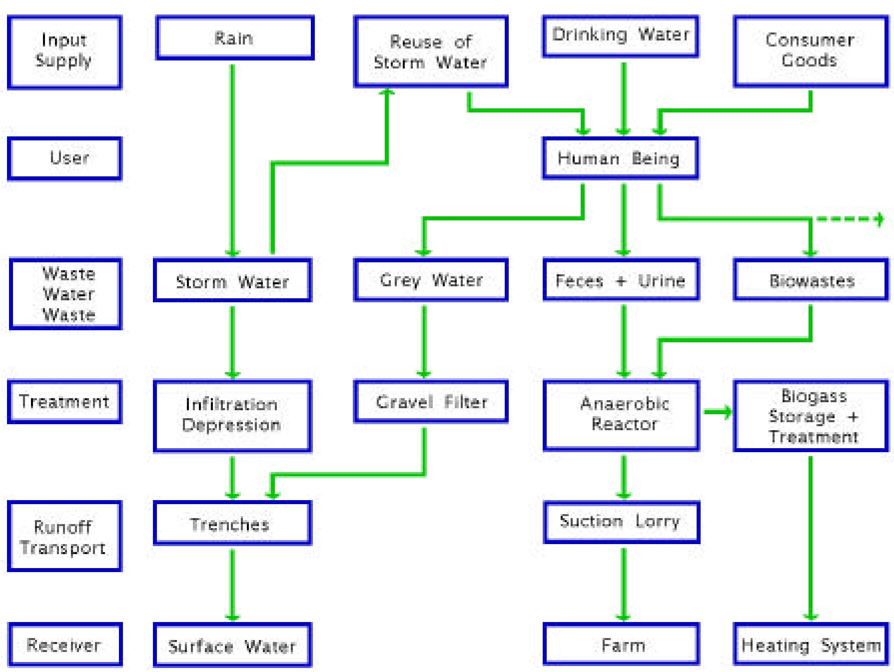


**Figure 3-12**. Flow chart of proposed integrated water system for Adelaide, Australia (Clark et al. 1997).

## Simulated Monthly Urban Water Budgets for Denver and New York

### *General*

This section presents the results of monthly simulations of water budgets for cities with climates similar to New York and Denver. The results should not be construed to be accurate representations of actual conditions in these two cities. The purpose of presenting these case studies is to show the relative importance of the various terms in the water budget and to show the impact of climatic conditions. The common assumptions for the comparative studies of representative urban neighborhoods in Denver and New York are presented in Table 3-9.

**Table 3-9**. Assumed common attributes of representative neighborhoods in Denver, CO and New York, NY.

| **Area, acres** | **Impervious Area Total** | **Impervious Area Directly Connected** | **100** |
|---|---|---|---|
| Roof area, acres | 15 | 5 | |
| Driveway area, acres | 10 | 5 | |
| Local street area, acres | 10 | 10 | |
| Major street area, acres | 5 | 5 | |
| Lawn area, acres | | | 60 |
| Directly connected imperviousness, DCI, % | | | 25 |
| People | | | 1,000 |

### *Water Use*

#### Indoor Water Use

Assumed per capita water use estimates for the two cities are shown in Table 3-10.

**Table 3-10**. Assumed indoor water use for Denver, CO and New York, NY neighborhoods.

| **Item** | **Flow (gpcd)** | **% of Total** | **Black Water (gpcd)** | **Gray Water (gpcd)** |
|---|---|---|---|---|
| Toilets | 16 | 26.6 | 16 | |
| Showers | 10 | 16.7 | 10 | |
| Baths | 1 | 1.7 | 1 | |
| Faucet-drinking | 1 | 1.7 | 1 | |
| Faucet-other | 9 | 15.0 | 9 | |
| Dishwashers | 2 | 3.3 | 2 | |
| Clothes washers | 14 | 23.3 | 14 | |
| Leaks | 7 | 11.7 | 1 | 6 |
| Total | 60 | 100 | 54 | 6 |

The land use for the two representative neighborhoods is typical low density residential.  The same population density of 10 persons per acre is used for the Denver and New York because since the purpose of this exercise is to illustrate the impact of rainfall and climate.

### Outdoor Water Use

The estimated outdoor water use for the two cities is shown in Table 3-11.

**Table 3-11**. Estimated monthly outdoor water use in Denver, CO and New York, NY.

| Month | Denver (gpcd) | New York (gpcd) |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0 | 0 |
| 3 | 15 | 0 |
| 4 | 50 | 0 |
| 5 | 90 | 40 |
| 6 | 175 | 70 |
| 7 | 210 | 100 |
| 8 | 175 | 70 |
| 9 | 70 | 30 |
| 10 | 20 | 0 |
| 11 | 0 | 0 |
| 12 | 0 | 0 |
| Mean | 67 | 26 |

Inspection of Table 3-11 indicates that the per capita outdoor water use of 67 gpcd for this prototype area in Denver exceeds the indoor water use of 60 gpcd whereas average annual outdoor water use on New York of 26 gpcd is less than one half of the indoor water use because New York receives more annual precipitation and has lower evapotranspiration needs than Denver.  Peak water use occurs during the summer in both locations and most of that peak is caused by lawn watering. Denver's peak monthly outdoor water use of 210 gpcd is over three times the indoor water use during July.  Thus, urban lawn watering is the dominant component in peak water use in most urban areas.  Peak water use is an important factor in sizing water infrastructure.

### Total Water Use

Total water use (indoor plus outdoor) for Denver and New York is shown in Table 3-12.

**Table 3-12**. Total monthly water use for representative residential areas in Denver, CO and New York, NY.

Total Water Use for Denver

| Month | Black Water (gpcd) | Gray Water (gpcd) | Total (gpcd) | Outdoor (gpcd) | Total (gpcd) |
|---|---|---|---|---|---|
| 1 | 17 | 43 | 60 | 0 | 60 |
| 2 | 17 | 43 | 60 | 0 | 60 |
| 3 | 17 | 43 | 60 | 15 | 75 |
| 4 | 17 | 43 | 60 | 50 | 110 |
| 5 | 17 | 43 | 60 | 90 | 150 |
| 6 | 17 | 43 | 60 | 175 | 235 |
| 7 | 17 | 43 | 60 | 210 | 270 |
| 8 | 17 | 43 | 60 | 175 | 235 |
| 9 | 17 | 43 | 60 | 70 | 130 |
| 10 | 17 | 43 | 60 | 20 | 80 |
| 11 | 17 | 43 | 60 | 0 | 60 |
| 12 | 17 | 43 | 60 | 0 | 60 |
| Mean | 17 | 43 | 60 | 67 | 127 |

Total Water Use for New York

| Month | Black Water (gpcd) | Gray Water (gpcd) | Total (gpcd) | Outdoor (gpcd) | Total (gpcd) |
|---|---|---|---|---|---|
| 1 | 17 | 43 | 60 | 0 | 60 |
| 2 | 17 | 43 | 60 | 0 | 60 |
| 3 | 17 | 43 | 60 | 0 | 60 |
| 4 | 17 | 43 | 60 | 0 | 60 |
| 5 | 17 | 43 | 60 | 40 | 100 |
| 6 | 17 | 43 | 60 | 70 | 130 |
| 7 | 17 | 43 | 60 | 100 | 160 |
| 8 | 17 | 43 | 60 | 70 | 130 |
| 9 | 17 | 43 | 60 | 30 | 90 |
| 10 | 17 | 43 | 60 | 0 | 60 |
| 11 | 17 | 43 | 60 | 0 | 60 |
| 12 | 17 | 43 | 60 | 0 | 60 |
| Mean | | 43 | 60 | 26 | 86 |

Histograms of monthly water use for Denver and New York are shown in Figures 3-13 and 3-14. Per capita indoor residential water use is the same for the two cities with only 17 gpcd of the water use producing black water and 43 gpcd of gray water. There is very little monthly variability in indoor water use. On the other hand, outdoor water use varies widely over the year and is the predominant cause of peak water use.

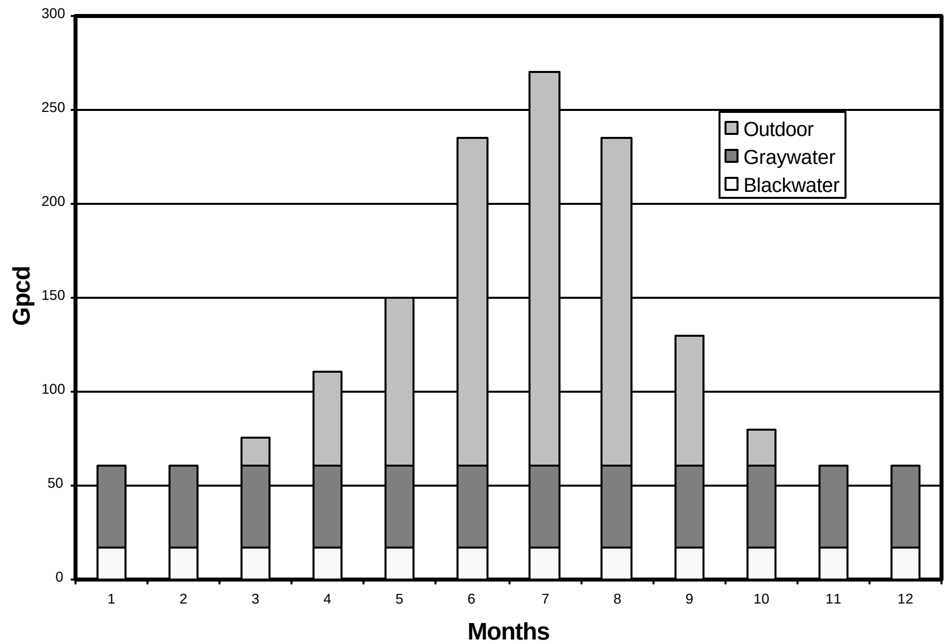


**Figure 3-13**. Average water use, Denver, CO.

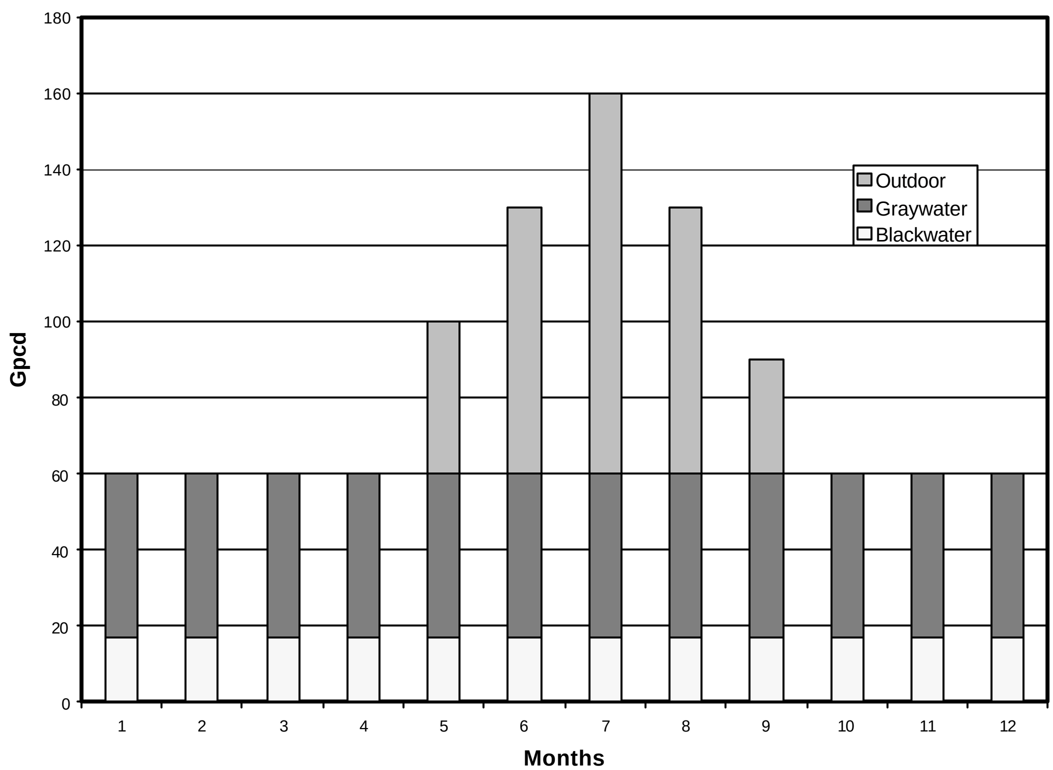


**Figure 3-14**. Average water use, New York, NY.

### *Wastewater*

Wastewater or DWF = indoor water use residual + I/I. Nearly all of indoor water use enters the sanitary sewer system. Small losses in indoor water use, (e.g., from taking water on a picnic), are probably offset by the discharge to the sewer system of fluids brought into the house that are poured down the drains (e.g. leftover soft drink). Thus, it is reasonable to assume that 100% of the indoor water use, or its equivalent, enters the wastewater system. Salient assumptions used in the Denver-New York analysis are:

- Indoor water use residuals: Assume 100% of indoor water use goes to the sanitary or combined sewer. This component is DWF.
- Infiltration/inflow: I/I = base infiltration + rain-induced inflow and infiltration. Infiltration varies widely depending on construction and maintenance practices. Sanitary sewers are designed for two to six times DWF with the base sewer infiltration assumed to be 60 gpcd. Rain-induced infiltration, in gpcd, is computed as follows:
  - Denver, I = 60 times P(monthly inches)
  - New York, I = 20 times P(monthly inches)

The estimated I/I is presented for illustrative purposes and does not necessarily represent actual I/I for these two cities.

The total estimated wastewater flows for Denver, CO and New York, NY are shown in Figures 3-15 and 3-16 and Table 3-13. As with indoor and outdoor water use, black water and gray water associated with indoor water use are essentially constant throughout the year. However, I/I varies widely over the year and determines the design capacity for the wastewater network. Traditionally, I/I has been accepted as part of normal sewer flows. This topic is evaluated in Chapter 6.

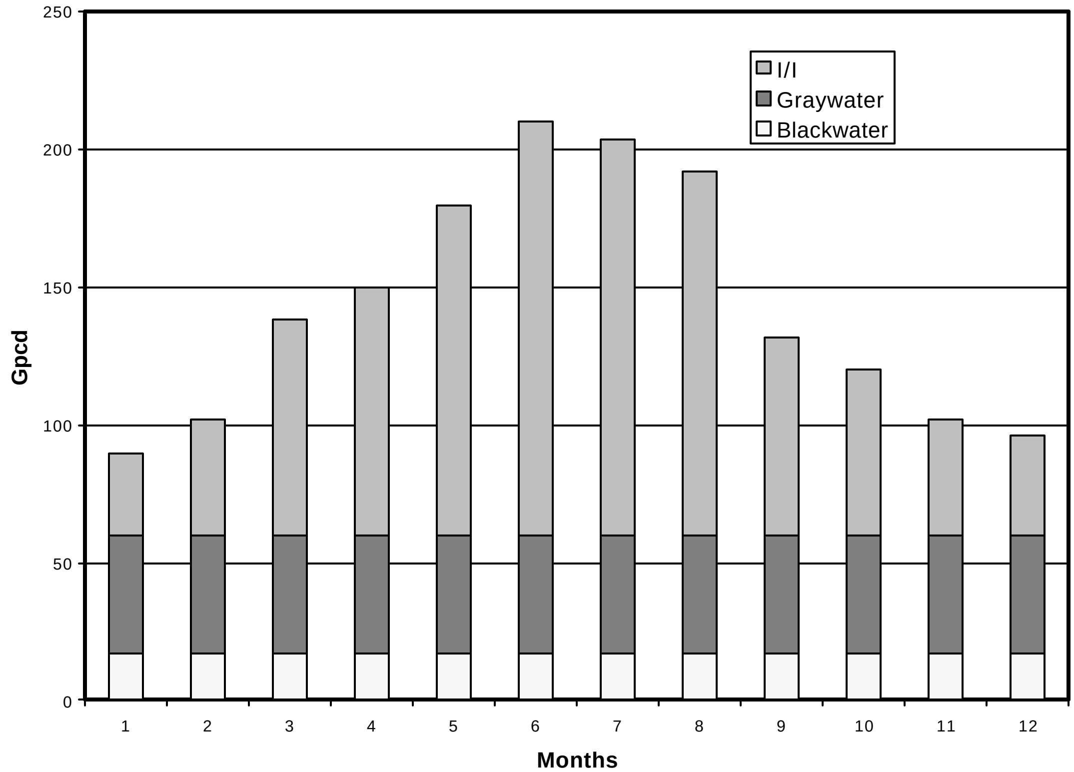


**Figure 3-15**. Monthly residential wastewater discharge, Denver, CO.

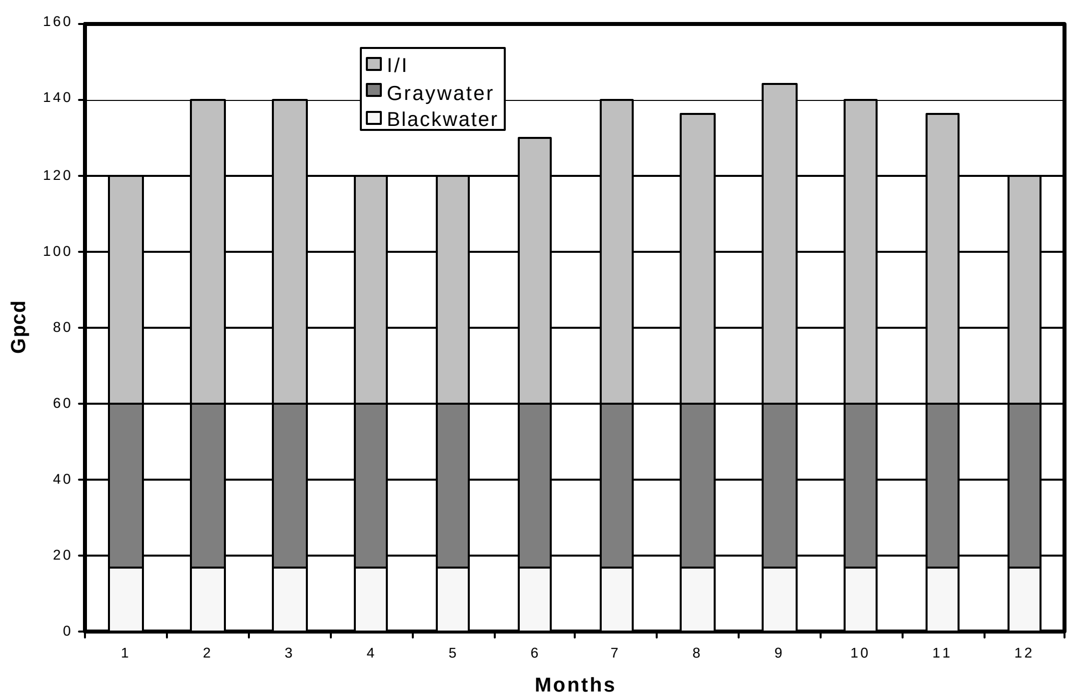


**Figure 3-16**. Monthly residential wastewater discharge, New York, NY.

**Table 3-13**. Total monthly wastewater flows for Denver, CO and New York, NY.

Denver

| Month | Precip. (inches) | Black Water (gpcd) | Gray Water (gpcd) | I/I (gpcd) | Total (gpcd) |
|---|---|---|---|---|---|
| 1 | 0.5 | 17 | 43 | 30 | 90 |
| 2 | 0.7 | 17 | 43 | 42 | 102 |
| 3 | 1.3 | 17 | 43 | 78 | 138 |
| 4 | 1.5 | 17 | 43 | 90 | 150 |
| 5 | 2.0 | 17 | 43 | 120 | 180 |
| 6 | 2.5 | 17 | 43 | 150 | 210 |
| 7 | 2.4 | 17 | 43 | 144 | 204 |
| 8 | 2.2 | 17 | 43 | 132 | 192 |
| 9 | 1.2 | 17 | 43 | 72 | 132 |
| 10 | 1.0 | 17 | 43 | 60 | 120 |
| 11 | 0.7 | 17 | 43 | 42 | 102 |
| 12 | 0.6 | 17 | 43 | 36 | 96 |
| Total | 17.0 | | | | |
| Mean | 1.38 | 17 | 43 | 83 | 143 |

New York

| Month | Precip. (inches) | Black Water (gpcd) | Gray Water (gpcd) | I/I (gpcd) | Total (gpcd) |
|---|---|---|---|---|---|
| 1 | 3.0 | 17 | 43 | 60 | 120 |
| 2 | 4.0 | 17 | 43 | 80 | 97 |
| 3 | 4.0 | 17 | 43 | 80 | 97 |
| 4 | 3.0 | 17 | 43 | 60 | 77 |
| 5 | 3.0 | 17 | 43 | 60 | 77 |
| 6 | 3.5 | 17 | 43 | 70 | 87 |
| 7 | 4.0 | 17 | 43 | 80 | 97 |
| 8 | 3.8 | 17 | 43 | 76 | 93 |
| 9 | 4.2 | 17 | 43 | 84 | 101 |
| 10 | 4.0 | 17 | 43 | 80 | 97 |
| 11 | 3.8 | 17 | 43 | 76 | 93 |
| 12 | 3.0 | 17 | 43 | 60 | 77 |
| Total | 43.0 | | | | |
| Mean | 3.61 | 17 | 43 | 72 | 93 |

### *Stormwater Runoff*

The final component of the urban water budget to be estimated is the quantity of stormwater runoff. General characteristics of the study areas were shown in Table 3-9.

The runoff volume, R, from precipitation, P, is estimated as R = C*P where C = runoff coefficient. This coefficient is assumed to equal the directly connected imperviousness, I. For this example, I = 0.25. The estimated monthly precipitation and runoff for Denver and New York are shown in Table 3-14.

**Table 3-14**. Monthly precipitation and runoff for Denver, CO and New York, NY.

| Month | Denver | | New York | |
|---|---|---|---|---|
| | Precipitation (inches) | Runoff (inches) | Precipitation (inches) | Runoff (inches) |
| 1 | 0.5 | 0.13 | 3.0 | 0.75 |
| 2 | 0.7 | 0.18 | 4.0 | 1.00 |
| 3 | 1.3 | 0.33 | 4.0 | 1.00 |
| 4 | 1.5 | 0.38 | 3.0 | 0.75 |
| 5 | 2.0 | 0.50 | 3.0 | 0.75 |
| 6 | 2.5 | 0.63 | 3.5 | 0.88 |
| 7 | 2.4 | 0.60 | 4.0 | 1.00 |
| 8 | 2.2 | 0.55 | 3.8 | 0.95 |
| 9 | 1.2 | 0.30 | 4.2 | 1.05 |
| 10 | 1.0 | 0.25 | 4.0 | 1.00 |
| 11 | 0.7 | 0.18 | 3.8 | 0.95 |
| 12 | 0.6 | 0.15 | 3.0 | 0.75 |
| Total | 16.6 | 4.15 | 43.3 | 10.83 |

### *Summary Water Budgets*

Water use and wastewater flows are typically expressed in terms of gallons per day. Stormwater runoff is usually expressed in inches averaged over the entire catchment. All flows were converted to inches averaged over the 100 acre catchment with 1,000 residents. The common assumed values, presented earlier in this analysis, are:

1. Population 1,000
2. Area, acres 100
3. Indoor water use, gpcd 60
4. Runoff coefficient 0.25
5. Conversion factors: 7.48 gallons = 1 cu ft
   43,560 sq ft = 1 acre

The summary results for Denver, CO and New York, NY are presented in Tables 3-15 and 3-16. Denver results indicate a natural input from precipitation of 16.6 inches per year and imported water of 17.15 inches per year, slightly more than the natural input. The majority of the imported water is used for lawn watering. On the output side for Denver, I/I at 11.19 inches is the largest source of the 19.26 inches of water going to the WWTP. Urban runoff contributes an additional 4.15 inches of water leaving the system. Nearly 40% of the urban runoff falls on roofs and driveways. A good portion of that water could be retained on-site and infiltrated and/or used for lawn watering. Urban runoff alone is insufficient to provide sufficient water for lawn watering. However, urban runoff and graywater do provide enough water to meet essentially all of the lawn watering needs.

New York results indicate a natural input from precipitation of 43.3 inches per year and imported water of 11.57 inches per year, slightly more than a quarter of the natural input. The majority of the imported water is used for indoor purposes. On the output side for New York, I/I at 9.69 inches is the largest source of the 17.76 inches of water going to the WWTP. Urban runoff contributes an additional 10.83 inches of water leaving the system. Nearly 40% of the urban runoff falls on roofs and driveways. A good portion of that water could be retained on-site and infiltrated and/or used for lawn watering. Urban runoff alone is sufficient to provide sufficient water for lawn watering.

**Future Urban Water Scenarios**

Future scenarios for urban water use and wastewater discharges include combinations of the following futures. Water use estimates in gallons per capita per day include the pro rata additional nonresidential use, which is included in the per capita figure.

- Status Quo: This scenario means continuing the current pattern of water use and wastewater disposal. The nationally mandated compulsory use of low flush toilets should reduce per capita consumption by 10-15 gpcd. Legitimate sewage quantities should be in the 75-90 gpcd range. This per capita figure includes the added water use of non-residential customers averaged over the residential population. I/I would add another 50 to 400 gpcd to these flows. Solids loading will remain the same; thus, DWF concentrations will increase accordingly.
- Significant indoor water conservation: This scenario means replacing existing plumbing systems with water conserving devices including low-flush toilets, low flow rate shower heads, lower water using appliances. Expected sewage quantities are in the 50-65 gpcd range. Some I/I control is expected which reduces I/I to 25 to 300 gpcd. Increased DWF concentrations are expected.
- Gray water systems with aggressive I/I control: This scenario is defined as the preceding scenario with on-site use of gray water for lawn watering and toilet flushing. Expected sewage quantities are in the 30-45 gpcd range. Also assumed is aggressive I/I control, which reduces I/I to 25 to 100 gpcd. Much higher DWF concentrations will occur.

Thus, future water conservation and I/I control practices can be expected to have a significant impact on wastewater discharges or dry-weather flow. Having to deal with much lower volumes of water opens up opportunities for innovative stormwater management.  For example, Pruel (1996) suggests storing DWF on-site during wet-weather periods.  If only black water has to be stored, then this option becomes more attractive.

**Table 3-15**. Final monthly water budget for Denver, CO.

Monthly
(All values are in inches)

| Month | Precip-itation | Indoor Water Use | Outdoor Water Use | Total | DWF | I/I | Total | Urban Runoff | Days/month |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.5 | 0.69 | 0.00 | 0.69 | 0.69 | 0.34 | 1.03 | 0.13 | 31 |
| 2 | 0.7 | 0.62 | 0.00 | 0.62 | 0.62 | 0.43 | 1.05 | 0.18 | 28 |
| 3 | 1.3 | 0.69 | 0.17 | 0.86 | 0.69 | 0.89 | 1.58 | 0.33 | 31 |
| 4 | 1.5 | 0.66 | 0.55 | 1.22 | 0.66 | 0.99 | 1.66 | 0.38 | 30 |
| 5 | 2.0 | 0.69 | 1.03 | 1.71 | 0.69 | 1.37 | 2.06 | 0.50 | 31 |
| 6 | 2.5 | 0.66 | 1.93 | 2.60 | 0.66 | 1.66 | 2.32 | 0.63 | 30 |
| 7 | 2.4 | 0.69 | 2.40 | 3.08 | 0.69 | 1.64 | 2.33 | 0.60 | 31 |
| 8 | 2.2 | 0.69 | 2.00 | 2.68 | 0.69 | 1.51 | 2.19 | 0.55 | 31 |
| 9 | 1.2 | 0.66 | 0.77 | 1.44 | 0.66 | 0.80 | 1.46 | 0.30 | 30 |
| 10 | 1.0 | 0.69 | 0.23 | 0.91 | 0.69 | 0.69 | 1.37 | 0.25 | 31 |
| 11 | 0.7 | 0.66 | 0.00 | 0.66 | 0.66 | 0.46 | 1.13 | 0.18 | 30 |
| 12 | 0.6 | 0.69 | 0.00 | 0.69 | 0.69 | 0.41 | 1.10 | 0.15 | 31 |
| Total | 16.6 | 8.07 | 9.08 | 17.15 | 8.07 | 11.19 | 19.26 | 4.15 | 365 |

Annual
(All values are in inches)

| **Inputs:** | | | **Quality Aspects** |
|---|---|---|---|
| Precipitation | | 16.60 | High quality |
| Indoor use | | 8.07 | |
| Black water | 2.29 | | Could use low quality |
| Gray water | 5.78 | | Need high quality |
| Outdoor use | | 9.08 | Need moderate quality |
| Total | | 33.75 | |
| **Outputs:** | | | |
| Wastewater | | | |
| Legitimate | | 8.07 | Requires high level of treatment |
| I/I | | 11.19 | Requires modest level of treatment |
| Urban runoff | | 4.15 | Requires little or no treatment |
| Roofs | 0.83 | | Requires little or no treatment |
| Driveways | 0.83 | | Requires little or no treatment |
| Local streets | 1.66 | | Requires little treatment |
| Major streets | 0.83 | | Requires moderate treatment |
| Sub-total, outputs | | 23.41 | |
| Recharge to local receiving waters and groundwater | | 10.34 | Good quality because of subsurface infiltration |
| Total | | 33.74 | |

**Table 3-16**. Final monthly water budget for New York, NY.

Monthly
(All values are in inches)

| Month | Precip-itation | Indoor Water Use | Outdoor Water Use | Total | DWF | I/I | Total | Urban Runoff | Days/month |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.0 | 0.69 | 0.00 | 0.69 | 0.69 | 0.69 | 1.37 | 0.75 | 31 |
| 2 | 4.0 | 0.62 | 0.00 | 0.62 | 0.62 | 0.82 | 1.44 | 1.00 | 28 |
| 3 | 4.0 | 0.69 | 0.00 | 0.69 | 0.69 | 0.91 | 1.60 | 1.00 | 31 |
| 4 | 3.0 | 0.66 | 0.00 | 0.66 | 0.66 | 0.66 | 1.33 | 0.75 | 30 |
| 5 | 3.0 | 0.69 | 0.46 | 1.14 | 0.69 | 0.69 | 1.37 | 0.75 | 31 |
| 6 | 3.5 | 0.66 | 0.77 | 1.44 | 0.66 | 0.77 | 1.44 | 0.88 | 30 |
| 7 | 4.0 | 0.69 | 1.14 | 1.83 | 0.69 | 0.91 | 1.60 | 1.00 | 31 |
| 8 | 3.8 | 0.69 | 0.80 | 1.48 | 0.69 | 0.87 | 1.55 | 0.95 | 31 |
| 9 | 4.2 | 0.66 | 0.33 | 0.99 | 0.66 | 0.93 | 1.59 | 1.05 | 30 |
| 10 | 4.0 | 0.69 | 0.00 | 0.69 | 0.69 | 0.91 | 1.60 | 1.00 | 31 |
| 11 | 3.8 | 0.66 | 0.00 | 0.66 | 0.66 | 0.84 | 1.50 | 0.95 | 30 |
| 12 | 3.0 | 0.69 | 0.00 | 0.69 | 0.69 | 0.69 | 1.37 | 0.75 | 31 |
| Total | 43.3 | 8.07 | 3.5 | 11.57 | 8.07 | 9.69 | 17.76 | 10.83 | 365 |

Annual
(All values are in inches)

| **Inputs:** | | | **Quality Aspects** |
|---|---|---|---|
| Precipitation | | 43.30 | High quality |
| Indoor use | | 8.07 | |
| Black water | 2.29 | | Could use low quality |
| Gray water | 5.78 | | Need high quality |
| Outdoor use | | 3.50 | Need moderate quality |
| Total | | 54.87 | |
| **Outputs:** | | | |
| Wastewater | | | |
| Legitimate | | 8.07 | |
| Blackwater | 2.29 | | Requires high level of treatment |
| Graywater | 5.78 | | Requires modest level of treatment |
| I/I | | 9.69 | Requires little or no treatment |
| Urban runoff | | 10.83 | |
| Roofs | 2.17 | | Requires little or no treatment |
| Driveways | 2.17 | | Requires little or no treatment |
| Local streets | 4.33 | | Requires little treatment |
| Major streets | 2.17 | | Requires moderate treatment |
| Sub-total, outputs | | 23.41 | |
| Recharge to local receiving waters and groundwater | | 26.29 | Good quality because of subsurface infiltration |
| Total | | 54.87 | |

## References

Basta, D.J. and B.T. Bower (Eds.) (1982). Analyzing Natural Systems: Analysis for Regional Residuals-Environmental Quality Management. Resources for the Future, Inc. Washington, D.C.

Cantor, K.P., R. Hoover, P. Hartage et al. (1987). Bladder cancer, drinking water source, and tap water consumption. J. National Cancer Institute. 79(6): 1269-1279.

Clark, R., A. Perkins and S.E. Wood (1997). Water Sustainability in Urban Areas-An Adelaide and Regions Case Study. Report One - An Exploration of the Concept. Dept. of Environment and Natural Resources. Adelaide, Australia. Draft.

Courtney, B.A. (1997). An Integrated Approach to Urban Irrigation: The Role of Shading, Scheduling, and Directly Connected Imperviousness. MS Thesis, Dept. of Civil, Environmental, and Architectural Engineering. U. of Colorado. Boulder, CO.

Denver Water (1997). Comprehensive Annual Financial Report for the Year Ended December 31, 1996. Denver, CO.

DeOreo, W., J. Heaney and P. Mayer (1996). Flow Trace Analysis to Assess Water Use. Journal of the American Water Works Association. Jan., p. 79-80.

Edwards, K. and L. Martin (1995). A Methodology for Surveying Domestic Water Consumption. Journal of the Chartered Institution of Water and Environmental Management. Vol. 9, No. 5., p. 47-489.

Foster, K. E., M. M. Karpiscak and R. G. Brittain (1988a). Casa Del Agua: A Residential Water Conservation and Reuse Demonstration Project in Tucson, AZ. Water Resources Bulletin. 24(6):1201-1206.

Foster, K. E., M. M. Karpiscak and R. G. Brittain (1988b). Casa Del Agua: A Residential Water Conservation and Reuse Demonstration Project in Tucson, AZ. Water Resources Bulletin. 24(6), p. 1201-1206.

Friedler, E., D.M. Brown, and D. Butler (1996). A Study of WC Derived Sewer Solids. Water Science and Technology. Vol. 33, No. 9, p. 17-24.

Fujita, S. (1996). Measures to promote stormwater infiltration. Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 407-412.

Grimmond, C. S. B., T. R. Oke and D. G.Steyn (1986a). Urban Water Balance 1. A Model for Daily Totals. Water Resources Research. 22(10):1397-1403.

Grimmond, C. S. B. and T. R. Oke (1986b). Urban Water Balance 2. Results from a Suburb of Vancouver, British Columbia. Water Resources Research. 22(10):1404-1412.

Grotter, M., and R. Otterpohl (1996). Integrated Urban Water Concept. Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 1801-1806.

Harpring, J. S. (1997). Nature of Indoor Residential Water Use. MS Thesis, Dept. of Civil, Environmental, and Architectural Engineering. U. of Colorado. Boulder, CO.

Heaney, J.P. (1994). Towards Integrated Urban Water System Management. Proc. HEC Workshop on Future Directions of Urban Hydrology. Davis, CA.

Heaney, J.P., L. Wright and Samsuhadi (1996). Risk Analysis in Urban Stormwater Quality Management. in Haimes, Y.Y., Moser, D.A., and E.Z. Stakhiv, (Eds.) Risk-Based Decision Making in Water Resources VII. ASCE. New York, NY. p. 219-248.

Henze, M., L. Somlyody, W. Schilling, and J. Tyson (Eds.) (1997). Sustainable Sanitation. Water Science and Technology. Vol. 35, No. 9.

Herrmann, T. and U. Klaus (1996). Fluxes of nutrients in urban drainage systems: assessment of sources, pathways and treatment technologies. Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 761-766.

Imbe, M., T. Ohta and N. Takano (1996). Quantitative Assessment of Improvement in Hydrological Water Cycle in Urbanized River Basin. Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 1085-1090.

Johnson, H., T.A. Stanstrom, J.S. Svensson, and A. Sandin (1997). Source-Separated Urine-Nutrient and Heavy Metal Contents Water Saving and Fecal Contamination. Water Science and Technology. Vol. 35, No. 9, p. 45-152.

Jones, D. E. (1971). Urban Water Resources Management Affects the Total Urban Picture. Chapter 1F in Albertson, M.L., Tucker, L.S., and Taylor, D.C. (Eds.) Treatise on Urban Water Systems. Colorado State University. Ft. Collins, CO.

Joyce, J. (1995). Odor and Corrosion Control in Collection System: A Growing Problem? Water Environment federation. Sewers of the Future. Alexandria, VA. P.9-1 to 9-12.

Karpiscak, M. M., K. E. Foster and N. Schmidt (1990). Residential Water Conservation: Casa Del Agua. Water Resources Research. 26(6):939-948.

Karpiscak, M.M., R.G Brittain and K.E. Foster (1994). Desert House: A Demonstration/Experiment in Efficient Domestic Water and Energy Use. Water Resources Bulletin. Vol. 30, No. 2, p. 329-334.

Law, I. (1997). Domestic Non-potable Reuse – Why Even Consider it? Water, May/June.

Kneese, A.V., R.U. Ayres and R.C. d'Arge (1970). Economics and the Environment- A Materials Balance Approach. The Johns Hopkins Press. Baltimore, MD.

Maddaus, W.O. (1987). Water Conservation. American Water Works Association. Denver, CO.

Mayer (1995). Residential Water Use and Conservation Effectiveness: A Process Approach. Master's Thesis, University of Colorado. Boulder, CO.

Mayer, P. W., W. B. De Oreo, J. O. Nelson, E. Opitz and R. Allen (1997). North American Residential End Use Study Progress Report to American Water Works Association Research Foundation. Denver, CO.

McPherson, M.B. (1973). Need for Metropolitan Water Balance Inventories. Jour. of the Hydraulics Div. ASCE. 99, HY10, p. 1837-1848.

McPherson, M.B. et al. (1968). Systematic Study and Development of Long-Range Programs of Urban Water Resources Research. Report to Office of Water Resources Research. NTIS No. PB 184 318. Washington, D.C.

Mitchell, V.G., R.G. Mein and T.A. McMahon (1996). Evaluating the Resource Potential of Stormwater and Wastewater: an Australian Perspective. Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 1293-1298.

Nelen, A.J.M., A.C. de Ridder and E.C. Hartman (1996b). Planning of a New Urban Area in a Municipality of Ede. Using a New Approach to Environmental Protection.

Pruell, H.C. (1996). Combined Sewage Prevention System (CSPS) for Domestic Wastewater Source Control. In Proceedings of the 7$^{th}$ International Conference on Urban Storm Drainage. Hannover, Germany. P. 193-198.

Sakrison, R.G. (1996). New Urbanism, Growth Management and the Effect on Metropolitan Water demands. Proc. of Conserv 96, ASCE, AWRA, and AWWA. Orlando, FL. p. 19-26.

Sieker, F. and H-R. Verworn. (Eds.). Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 259-264.

Stephenson, D. (1996). Evaluation of Effects of Urbanization on Storm Runoff. Proceedings of the 7th International Conference on Urban Storm Drainage. Hannover, Germany. p. 31-36.

Stadjuhar, L. (1997). Outdoor Residential Water Use. Master's Thesis, University of Colorado. Boulder, CO.

US Environmental Protection Agency (USEPA) (1979). 1978 Needs Survey Cost Methodology for Control of Combined Sewer Overflow and Stormwater Discharges. EPA-430/9-79-002. Washington, DC.